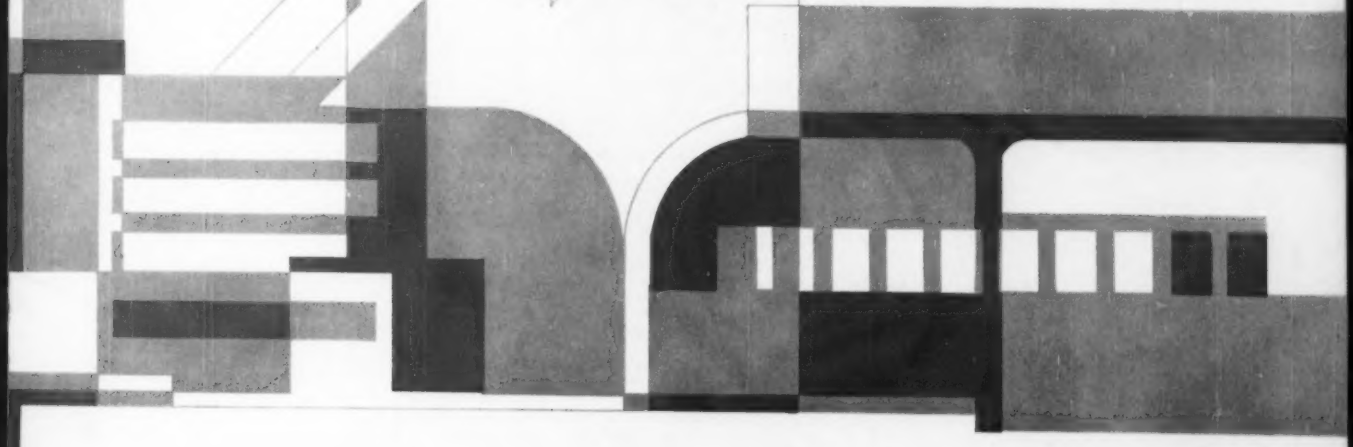
JULY-AUGUST-1959
VOLUME X
NUMBER 4

# the journal of INDUSTRIAL ENGINEERING

THE RESEARCH LABORATORY
By N. Perkowski ..... 255
BETTER WORK STANDARDS THROUGH STATISTICAL TIME ANALYSIS
By Sidney Smith ..... 261
AN APPLICATION OF QUEUEING THEORY FOR DETERMINING MANPOWER REQUIREMENTS FOR AN IN-LINE ASSEMBLY INSPECTION DEPARTMENT
By Lawrence J. Sespaniak ..... 265
THE ORGANIZATION OF CONTROLLERSHIP
By E. B. Cochran ..... 268
LEAST-COST TESTING SEQUENCE
By H. Walter Price ..... 278
THE PRODUCTION OF VALUES ADDED BY MARKETING
By Al N. Seares ..... 280
THE APPLICATION OF SAMPLE SURVEY METHODOLOGY TO WORK SAMPLING
By Albert Mindlin ..... 286
SIMULATION AS A PRODUCTION AID
By John L. Colley, Jr. ..... 296
INVENTORYING FOR UNKNOWN DEMAND
By William T. Morris ..... 299
CYCLIC SERVICING
By Thomas F. O'Connor ..... 303
OPERATIONS RESEARCH IN MANAGEMENT PLANNING AND CONTROL
By W. J. McGuire ..... 308
THE DESIGN OF A FORCE PLATFORM FOR WORK MEASUREMENT
By James H. Greene and W. H. M. Morris ..... 312
THE INDEPENDENCE OF PACE RATING VERSUS WEIGHT HANDLED
By C. B. Gambrell, Jr. ..... 318
SUMMARY OF THE INDUSTRIAL ENGINEERING SYMPOSIUM, THE UNIVERSITY OF IOWA, NOVEMBER, 1958 ..... 323
INSTITUTE INTERESTS ..... 327
PRESIDENT'S MESSAGE
By Frank J. Johnson ..... 332
I. E. OPPORTUNITIES ..... 334



OFFICIAL PUBLICATION OF THE AMERICAN INSTITUTE OF INDUSTRIAL ENGINEERS, INC.

**AMERICAN INSTITUTE OF INDUSTRIAL ENGINEERS, INC.**

NATIONAL OFFICERS, 1959-1960

*President*
FRANK J. JOHNSON
863 Wellesley Drive, N.W.
Atlanta 5, Georgia

*First Vice President*
JACK F. JERICHO
United Air Lines
Chicago 38, Illinois

*Vice Presidents*
REGION I
WILLIAM J. VALLETTE
CBS Electronics
Danvers, Massachusetts

REGION II
LEROY O. GILLETTE
1829 Rockford Lane
Lancaster, Pennsylvania

REGION III
CHARLES G. HOWARD
American Viscose Corp.
Nitro, West Virginia

REGION IV
JOHN A. NATTRESS
P. O. Box 2177
Gainesville, Florida

REGION V
JAMES A. RICHARDSON
185 Shirewood Drive
Rochester 10, New York

REGION VI
WILLIAM N. BRYANT
614 Chippewa Drive
Jeffersonville, Indiana

REGION VII
JOHN L. IMHOFF
University of Arkansas
Fayetteville, Arkansas

REGION VIII
ARTHUR E. ARONSON
A. B. Dick Company
Chicago 48, Illinois

REGION IX
ARTHUR L. ZIEGELMEYER, JR.
2900 Gardenia Drive
Fort Worth 19, Texas

REGION X
CARL F. KAISER
18961 Fernbrook Court
Saratoga, California

*Treasurer*
RALPH W. UPDEGRAFF
4424 Seventh Street, S. W.
Canton 10, Ohio

*Executive Secretary*
FLOYD J. TITLER
AIIE National Headquarters
145 North High Street
Columbus 15, Ohio

*Board Members-at-Large*
WARREN E. ALBERTS
United Air Lines
Chicago 38, Illinois

JAMES D. NORDAHL
P. O. Box 71
Livermore, California

ALEX W. RATHE
165 Westchester Avenue
Thornwood, New York

ROBERT H. ROY
The Johns Hopkins University
Baltimore 18, Maryland

*Past Presidents*
GEORGE H. GUSTAT (11)
GORDON B. CARSON (10)
HOWARD P. EMERSON (9)
E. L. SLAGLE (8)
D. G. MALCOLM (7)
F. F. GROSECLOSE (6)
M. A. PAYNE (5)
JOHN D. COLEMAN (4)
ROBERT E. ALLAN (3)
DWIGHT D. GARDNER (2)
ELDON D. RANEY (1)

*Founder*
WYLLYS G. STANTON

**the journal of**

# INDUSTRIAL ENGINEERING

**OFFICIAL PUBLICATION OF THE AMERICAN INSTITUTE OF INDUSTRIAL ENGINEERS, INC.**

***Published Bi-monthly*** **• AIIE Headquarters and Publication Offices, 145 North High Street, Columbus 15, Ohio •** ***Editorial Office*****—A. French Building, 225 North Avenue, N.W., Atlanta 13, Georgia**

**EDITORIAL STAFF**

*Editor-in-Chief*
ROBERT N. LEHRER
The Technological Institute
Northwestern University

*Editor*
CECIL G. JOHNSON
Georgia Institute of Technology

*Monograph Editor*
HAROLD O. DAVIDSON
Operations Research, Inc.

*Institute Interests Editor*
NELSON K. ROGERS
Pan-Atlantic Steamship Corporation

*Recent Readables Editor*
GEORGE L. ANTON
Ethyl Corporation

*Editorial Assistant*
EMMA B. DONNELLY
Journal of Industrial Engineering

*Business Manager*
JACK R. WALKER
Georgia Institute of Technology

*Circulation Manager*
TEE H. HIETT
Georgia Institute of Technology

**EDITORIAL BOARD**

F. F. GROSECLOSE, *Chairman*
Georgia Institute of Technology

JOHN M. ALLDERIGE
Eastman Kodak Company

WILSON J. BENTLEY
Oklahoma State University

DANIEL J. DUFFY
Polytechnic Institute of Brooklyn

ROBERT M. EASTMAN
University of Missouri

HERBERT J. GROELINGER
System Development Corporation

M. D. KILBRIDGE
University of Chicago

ALAN J. LEVY
Management Consultant

DONALD G. MALCOLM
System Development Corporation

WILLIAM T. MORRIS
Ohio State University

ROBERT H. ROY
The Johns Hopkins University

M. E. SALVESON
Center for Advanced Management

AUSTIN WESTON
Western Printing and Lithographing Company

Copyright 1959 by The American Institute of Industrial Engineers, Inc. Reprint permission available from the Editorial Offices.

AIIE accepts no responsibility in connection with any liability which might develop as a result of articles published, for the opinions expressed are those of the authors and do not necessarily represent the Institute.

**Subscription Prices:** $10.00, one year; $17.00, two years.

**Single Issue Price:** Ninth National Conference Proceedings Issue $5.00, members; $7.00, non-members; other issues $2.50.

**All Manuscripts** for review should be submitted with drawings suitable for reproduction to the Editor-in-Chief, Journal of Industrial Engineering, A. French Building, 225 North Avenue, N.W., Atlanta 13, Georgia.

**Advertising Rates** available from Gordon Early & Sons, 100 N. LaSalle Street, Chicago 2, Illinois, Advertising Agent. Send copy and cuts to Journal of Industrial Engineering, A. French Building, 225 North Avenue, N.W., Atlanta 13, Georgia.

**Membership Information** available from AIIE Headquarters.

**Change of Address** notification should be submitted to AIIE Headquarters Office, 145 N. High Street, Columbus 15, Ohio.

► All issues of the *Journal of Industrial Engineering* are now available on microfilm to subscribers through University Microfilms, 313 N. First Street, Ann Arbor, Michigan.

Second-class postage paid at Columbus, Ohio and at additional mailing offices.

# The Research Laboratory

*by* **N. PERKOWSKI**[1]

*Assistant Professor, Department of Industrial Engineering,*
*University of Southern California, Los Angeles*

THE research laboratory can be defined as the total complex of an organization composed of men, equipment, and facilities that are dedicated to the pursuit of knowledge through the use of the scientific method in their investigations. It is within the framework of this definition that the discussion will subsequently be developed.

The ultimate recognition of the value of research to the economy and defense of a nation gave an impetus to the growth of research laboratories. For it is within the confines of these complexes of walls, flesh, and gadgets that scientific progress is continuously accelerated at an exponential rate. The research laboratory is, therefore, a factory for unveiling the fundamental truths of nature. It is a factory where these truths are used in developing projects useful to the human race.

Since the research laboratory is a shrine dedicated to the discovery of nature's secrets through research, it is worthwhile to pause briefly and explore the meaning of research. As Dr. Hertz puts it,

> As a basic premise, research may be defined as the application of human intelligence in a systematic manner to a problem whose solution is not immediately available (4).

This definition is sufficiently broad to encompass the individual worker, an informal team, and a highly organized group, working towards the solution of unique problems. Research, as we know it, implies the application of the scientific method in attacking a problem and the solution of a problem must be reproducible. The scientific method gives an efficient approach to the research problem and reproducibility measures the efficiency of research.

The research laboratories vary from garages in the alleys of a big city, the sedate walls of a university, to the modern giants, such as the Bell Laboratories or Hughes Aircraft Company. Yet, each one of them is a valid research laboratory. They all contribute to the store of knowledge.

Research expenditure on a national scale is very impressive. The McGraw-Hill economics department estimates that industry will invest $8.3 billion for research and development in 1958 and $9.9 billion by the year 1961. The importance of research can be further visualized, when it is appreciated that 50% of all products now in existence can be traced directly to results from a research laboratory (12, p. 23). The mighty force of research in our economy is confirmed by these facts.

A typical industrial research laboratory may be engaged in the entire spectrum of research and development. This spectrum includes endeavors from basic research to final production (5, p. 13).

## PRELIMINARY REMARKS

The purpose of this discussion is to explore some of the basic problems encountered in research laboratories. The problems to be defined are those confronted by the managers of present day laboratories Although the problems have been identified, their solutions, are not necessarily satisfactory in practice. It is believed that further concentration on these problems may bring desired results. The problems can be placed into two categories, which are as follows:

1. Administrative phases
2. Facilities planning and development

At the current activity level of research laboratories, the problems are well defined to the administrators. In particular, the problems associated with the administrative phases have been studied. This is only natural, because administrative aspects of a research laboratory are uniquely thorny as compared to other industrial administration. It is only in recent years that greater attention is given to facilities planning and development, although the research laboratories have not been able to develop a more definite pattern of their own in their physical structure. They are still bound to the traditionalism of the past.

The need for continuous study of these problems is apparent, when it is realized that the average cost per researcher is approximately $34,000 per year (12, p. 22). This is a considerable investment. As such it needs careful attention and cultivation, for the industrial history in recent years is abundant with examples of companies going into bankruptcy due to ill-conducted research activities.

[1] The author is indebted to Dr. John C. Scheib, Assistant Professor of Production Management, U.C.L.A., for his comments and suggestions on the manuscript.

## SCOPE OF RESEARCH PROJECTS

In the study of industrial laboratories, it is found that efforts will be devoted to a single area of science, or attempts will be made to acquire specialties in many disassociated fields. A typical example of a single area approach to research is the Bell Laboratories (2, p. 149). Their chief area of interest is the science of electrical communication. This area, however, proved to have considerable breadth and width, because it enabled this institution to make significant contributions in solid state physics, radar, and sound. Of course, many industrial research laboratories may restrict their investigation to an even narrower range of activities.

The scope of activities to be conducted by a particular laboratory is a management decision. This policy may be modified as the scientific developments warrant such changes. In recent years the change of activities of the airframe companies is most noticeable. Their interest is changing from strictly aerodynamic and structural analysis to the needs and requirements of space technology. The area of space technology appears to be even broader in scope than electronic communication systems.

The advantages of a single area approach are in permitting specialization in a particular field. In turn, this permits reaping the rewards of any products developed as a result of this research. The excellence of the telephone in the United States is due to the specialization of the Bell Laboratories in Telephony.

The multi-area approach assumes development of many specialized research fields. The areas of exploration are chosen in different fields, which may be chemistry, physics, and medicine. The basic disadvantage of this approach is that it resembles a shot gun approach to research even though the projects may be chosen with great care.

As a result, it is noticeable that this approach is most prevalent in the independent or university associated laboratories. A typical example of a multi-area research approach is the Stanford Research Institute. Their projects embrace the entire scientific spectrum. This type of industrial research is advantageous to the Stanford Research Institute, because they perform specific research for a client. In this manner they are able to survive as an institution.

Where do the ideas for research projects originate? Typically, the sources from which ideas are stimulated have been identified as follows (10, p. 21):

1. Outside the organization
   a. Government agencies
   b. Consumers and manufacturers
   c. Scientific Conferences
2. Within the Organization
   a. Technical persons
   b. Executive
   c. From previous work

Sufficient flexibility is provided to permit a project to originate at the various organizational levels. This makes it feasible to extract ideas for projects, which might otherwise be dormant.

## ADMINISTRATIVE PHASES

Administration of research requires more insight into the three common areas of managerial controls than in other industrial enterprises. The three areas of managerial controls are organization, personnel, and finance. This sophistication is required, because of the unique nature of work and the extremely high caliber of personnel employed. The standards of administration applied from other areas of endeavor would be doomed to failure in a research organization.

### ORGANIZATIONAL CONTROL

The organizational control of a research organization is required for the normal purposes of coordination of effort. The study of research laboratories indicates that they are formed along the following lines (5, p. 15):

1. Subject
2. Function
3. Mixture of the above types

The subject type of an organization is formed along definite divisions such as chemistry, electronics, physics, and applied mathematics. In turn, each division can be further subdivided by subjects unique to its specialty.

In the functional type organization, the formation is performed along definite functions such as pure research, product research, development, and product engineering. This also lends itself to further subdivision into smaller groups.

The third type of an organization for research would be a mixture of the two basic types. This would probably be found in larger research laboratories.

Mr. Voorhies points out the following essential elements for a research organization (9, pp. 13-14):

> Study of the manner in which the participating research groups are organized brings out the following basic elements which ultimately govern the general organization plan:
>
> 1. The basic pattern of the laboratory organization whether research effort is to be applied through divisions or groups arranged by (1) subjects, such as physics, chemistry, and mechanics, or (2) by functional arrangements for processes, products, and technical services.
> 2. The degree of self-containment—whether the research organization shall provide its own services, such as accounting, maintenance shop, and similar services or whether it shall be dependent upon others.
> 3. The degree of separation to be made between research functions on the one hand, and nontechnical administrative, control, and service functions on the other.

It is interesting to note that almost invariably the growth pattern of industrial research laboratories starts with the subject type organization. As it continues to grow, it changes to the functional type of an organization. Finally, as it becomes a large establishment, it takes on

the mixture form. This is natural, because the growth of a research organization imposes heavy problems of coordination which inevitably means a fairly complex form of organization. Although the basic organizational types have been identified, it cannot be said that further improvement is not possible. This area still offers fruitful potentialities for further study.

### PERSONNEL

It is, perhaps, in the area of personnel relations within a research laboratory that most investigative effort has been concentrated by research administrators. Inasmuch as many dollars were invested per researcher, the concern over personnel relations was a logical development. Apparent means were necessary to keep the modern research man not only satisfied with his position, but also to motivate him into creative effort. Efforts in personnel relations in research have been primarily concentrated on motivation of a researcher. In this field predominant credit is given to the Bell Laboratories, whose personnel policies are emulated in many key industrial laboratories throughout the country. They have signally influenced the form of salary compensation, promotion policies, and environmental working conditions for researchers.

The greatest apparent failure in personnel relations in a research laboratory is the inability to weld the disciplines of science and engineering into a harmonious unit. Each of these groups exhibits strong individual group cohesion. This failure is probably due to a lack of recognition of a fundamental method of approach on the part of each discipline. Whereas the scientist is interested in analysis and in adding fundamental formulas to the storeroom of knowledge, the engineer is more concerned in utilizing these bits of knowledge into a composite system. An effort must be made to bridge these two groups, for collective work on the part of both groups will even further enhance the role of modern research laboratories.

In the matter of recruitment of personnel, the laboratories seem to follow the policies of hiring the best in college graduates or experienced individuals. Older and established laboratories depend on their own pool of research men for their senior scientists with the new college graduates providing the new blood within the organization. The newer laboratories must go to the outside and hire the best senior individuals for particular skills.

In brief, the basic personnel policy is to give the researcher ample support to perform his work with a minimum of control and supervisory interference at an adequate salary. This policy has paid high dividends to leading research laboratories.

### FINANCIAL CONTROLS

Good financial controls are a must in research laboratories. Yet, they must be presented in an unobtrusive manner to the operating research personnel. The need for financial controls is obvious, since without adequate monetary brakes a given research project may run away with itself in terms of costs. Still the controls must not hinder nor be noxious to the research worker.

A unique difficulty arises in research and development financing of projects, because they do not lend themselves readily into cost comparisons with the past. Ratios of other companies or other projects usually are misleading. Perhaps the best current benchmark for budgeting is to ask, "How much did we spend last year? How much can we add (12, p. 24)?" This can be translated into percentage of company sales; however, even this type of a ratio is weak in its nature, because it does not state if too much or not enough is being spent on research. One company estimates that it spends $20 million annually on research to support $200 million worth of annual product. But it must be remembered that today's research may not be translated into next year's profits, the research effort is aimed 5 to 10 years from today.

The other difficulty, in financial controls is the researcher. For one reason or another most researchers dislike controls of any type. Financial controls are particularly obnoxious, because they represent an obstruction to many cherished projects. Even when the researcher reaches supervisory positions, he still has to overcome his dislike towards financial controls. In many research laboratories this requires considerable educational effort in the lower echelons of research supervision to overcome dislike of controls in the matter of finance.

Adequate budgeting appears to be the best approach currently available in financial controls. This approach provides a suitable basis for review and correction as projects are developed. It also gives a stable platform for comparison of progress in terms of money and time on particular projects.

## FACILITIES

The laboratory facilities represent the physical plant, which contains and aids the brainpower assembled for the purpose of conducting research. This plant must be designed for the singular purpose of supporting a research effort. Unfortunately few, if any, facilities have been thoroughly designed with a true systems approach for a research laboratory physical plant. Neither the architects nor research administrators have been capable of capturing the spirit of research facilities. To a large extent, they still resemble universities, factories, or modern financial buildings. This is undoubtedly due to a lack of extensive experience with this type of a physical plant. Convair's Astronautics facility and Bell Laboratories' Murray Hill facility are, perhaps, at present the closest to being the temples dedicated exclusively to research (2, p. 153).

Factors entering into consideration of physical facilities must be analyzed. They are as follows:

1. Location of Laboratory
2. Facility requirements
   a. Office requirements

b. Equipment requirements
c. Support groups

From the synthesis of the above needs, it is possible to evolve a physical plan for the laboratories. This plan must be carefully studied before execution, because it usually means a tremendous monetary expenditure to build facilities which will have a pronounced effect upon the efficiency of the research process.

LOCATION OF LABORATORY

The basic factors affecting location of research laboratories have been delineated in the literature (4, p. 293). Their respective actions upon the laboratory must be considered with as great precision as permitted by the available information.

The place of the research laboratory on the organization chart is considered to be the key factor in choosing a suitable site for its facilities (3, p. 309). For this determines its importance to the company and indicates, in turn, the support the company gives to its research organization.

In general the basic factors for laboratory location can be considered as follows:

1. Location of corporate offices
2. Location of other company facilities
3. Type or research being performed
4. Location and availability of cultural and educational facilities
5. Skilled personnel supply
6. Housing facilities
7. Location of other research establishments
8. Climate

Each one of these factors is almost as important as the other; therefore, they should not be considered to be ranked by weight. In a particular situation the research administration should rank the factors in importance, when they are uniquely determined for a given condition. Other factors may be considered, which are not listed, such as the particular problems of national security or desirability of a testing area in a remote section of the country; however, these latter factors are not general to all industrial research establishments.

OFFICE REQUIREMENTS

Next to site selection, the study of office requirements for research workers is the focal point in facility design. This is in contradiction to the normal view that laboratory equipment and facilities housing the equipment must come first, while the office space for researchers is of secondary importance. It is the author's experience that most researchers worry more about their offices than the equipment. They would probably be contented to have a junk shop for facilities, if their offices were only spacious and comfortable. Many an individual has changed positions simply because of office conditions. This reason for job changes is given in surprising numbers by researchers in private conversations. It is obvious, nevertheless, that the entire facility design will be governed both by the equipment and office requirements; however, it is desirable to focus strong attention on the office requirements.

In all likelihood the researcher considers the office as a status symbol. Since he must associate himself with a group, which provides him with the means for research in a chosen field, he also must give up considerable individuality. The office is the only vestige where he can feel free from the touch of the organization. The modern researcher is nowadays in the same psychological position as the artisans who were forced by the Industrial Revolution into factories to practice their trade. The modern research working and living conditions are, of course, not comparable. The days of conducting research in garages or sheds, because one was truly motivated, are pretty much gone due to equipment and means requirements for testing appropriate models. In effect, the modern researcher in research laboratories is also an organization man. This is in juxtaposition to his inbred individualism. This is probably the reason for the desire of many researchers to return to the universities, for the universities are the last vestiges for the individual.

The offices can be classified into three categories, which are as follows:

1. Individual
2. Open area
3. Combination of the first two types

The individual or one-man offices are the most desirable for research, but on the other hand they represent a high initial cost. Their chief disadvantages lie in difficulty of supervisory control and communications. But it is unquestioned that researchers are the happiest in this type of an office.

In direct opposition to the one-man office is the open area office or as it is sarcastically called the "bull pen" type office. In an open area the desks are simply positioned into rows upon rows. While this type of an office gives an extremely effective organizational control, it is undoubtedly the least efficient type of an office from the standpoint of work output. An individual feels he has completely lost his identity. It also develops, not unnaturally, a feeling of antagonism towards the company. In the long run, it is the most expensive type of an office that a company may develop on its premises.

The third type represents a compromise approach to the problem of cost, worker satisfaction, supervisory control and communication. In this type of an office an attempt is made to group small groups or sections as they work naturally together on a problem. In this situation, the size of an office varies, for it may contain 1, 3, or 10 individuals. The Hughes Aircraft Company is experiencing

considerable success with this type of office planning in their research laboratories.[2]

In office and laboratory planning, it is well to consider the modular type construction. For this type readily permits changes in the office and laboratory patterns as current activities of the laboratory demand such changes. Combining the module concept with movable walls gives the office planners an effective method for solving many difficult space problems. The following quote gives some illuminating thoughts on modular construction (3, p. 320):

> Functional planning in accordance with these criteria is greatly assisted by application of the module idea, one of the main motivating forces of modern architecture. A module is a repetitive space pattern. And it is a fact that, though modern laboratory research is so diverse in its techniques and operations, it is surprisingly uniform in its pattern of space occupancy.

The offices in research laboratories are an important factor to the success of future research. In their planning, consideration must be given to the intangible factors acting upon the research worker.

### LABORATORY EQUIPMENT AND SUPPORT SERVICES

The space requirement due to the amount and type of equipment will, of course, influence the ultimate design of the physical facilities of the laboratory. The requirements will vary from laboratory to laboratory. The important fact is to provide adequate space for the current requirements and to develop plans for expansion. It is surprising, how little thought is given to future expansion needs of a laboratory. Although, admittedly this is a difficult forecast to make, still an effort should be made to design a laboratory for at least a couple of years in advance of present day requirements.

In designing the laboratory equipment space requirement, it is necessary to consider all of the equipment. By this, it is meant not only the actual work benches and test equipment, but also the supporting machine shops, repair shops, and other needed facilities to service the equipment of work benches such as light, power, water, and ventilation.

It is also necessary to consider in the planning phase the need for support groups and their physical location to the research worker. In this class we can include the library, cafeteria, storage rooms, and any other specialized services to be provided in the laboratory. Not only their space requirements, but their particular location relative to research group is important in designing the physical laboratory facilities.

Dr. Hertz compiled a table for certain space requirements. It can be used as a guide in preliminary laboratory planning (4, p. 29).

[2] Observed by the author while a member of the Hughes 1958 School-Industry, Science, and Engineering Program.

TABLE 1

*Space Requirements for Research Organizations*

| Item | Space required (approximate) |
|---|---|
| Administrators | 140 sq. ft. (each) plus 3 sq. ft. of conference space for each member of the research group (minimum) |
| Clerical personnel | 70 sq. ft. each |
| Analysts | 100 sq. ft. each |
| Designers | 60–100 sq. ft. each |
| Creative laboratory workers including assistants | 175–225 sq. ft. each |
| Analytical laboratory workers | 100 sq. ft. each |
| Development workers | Depends upon the nature of the equipment, but no less than that for laboratory workers |
| Library | 200 sq. ft. per 1,000 volumes plus 100 sq. ft. per 50 professional workers in the laboratory |
| Craft shops | 10 per cent of total space provided for laboratory and development workers |
| Storage facilities | 5 per cent of total space provided for other purposes |
| Cafeteria | 25 sq. ft. per employee |
| Hallways, etc. | 20 per cent of total area |

### THE RESEARCH ATMOSPHERE

In planning a research laboratory an attempt should be made to capture within its physical confines the research atmosphere. It is difficult to define the quality of a research atmosphere, but undoubtedly such a quality does exist. One seeing a gothic style cathedral has no doubt that this is a place of worship. This style captured for centuries the definition of a church. A similar development must occur in the architecture of research laboratories.

Much has been written and discussed at conventions about the need for "university-like" look of a research laboratory. It is extremely doubtful that modern universities provide this atmosphere or outlook. This may have been true several decades ago, but present day universities are monstrosities of brick and mortar. Their main advantage lies in the comparative preservation of individualism among the faculty.

It is a challenge both to the research administrators, architects, and engineers to develop a laboratory that would capture within its physical confines the feel and touch of research.

The research laboratory of the future must have its own indelible feeling to the outsider. An individual should be able to identify the plant as a research center even though there might not be a sign to tell him that his assumptions are correct. An individual employed at this research laboratory should not even feel that he is working for somebody. This is an ideal. The achievement of this ideal is well worth the effort.

## RESEARCH GROUP INFLUENCE IN AN ORGANIZATION

The research activities have a direct influence on the organization, not only in terms of new products, but in

terms of new ideas and frequently, fresh thinking on many industrial approaches. This influence is most noticeable when the research laboratory is large in proportion to other activities within an organization. Its influence on other matters, besides, products, diminishes when the organization is large with multi-division operations. In many ways, in the latter type of a situation the ideas and thinking developed by the laboratory are first accepted and used by outside organizations and only then are they accepted by the parent organization.

This development argues strongly for the location of a research laboratory in proximity to the main corporate office and plants; however, this is not always possible to achieve in modern industry. The influence of a research laboratory on human relations, personnel policies, working conditions, and methods of approaching problems is great, when the laboratories are sufficiently close to other company activities. For closeness permits a mutual interchange of ideas.

The modern research laboratories have reached a new plateau in our industrial development. It is a matter of time only that other industrial activities will attempt to reach this same plateau. The research management has performed a remarkable feat in motivating men towards creative effort and at the same time either relaxing or toning down many of the old administrative controls.

Unfortunately, in too many laboratories, the influx of ideas is still an irreversible process, for the movement of men is from the laboratories to other organizational divisions. The reverse is not true. This particular condition must be corrected in the future, if the laboratories do not desire to outrun the realities of life. They can in time become ivory towers.

## CONCLUSIONS

In this discussion it was attempted to delineate some of the aspects of modern research laboratories. In the course of the discussion the areas of success in operations were noted and likewise the areas in which further effort might be rewarding were underlined.

The nearest problem with which the research laboratories are faced is that in the pell mell growth of recent years coupled with the startling successes, they are in danger of patting themselves too much on the back. As a result they may become overawed with their own achievements. The research administration should review itself periodically in a critical manner to avoid this development which would be detrimental to their immediate growth.

For the long range, administrators should develop their own investigations into the following areas:

1. Development of the physical characteristics of a laboratory along functional lines
   a. Improved architecture
   b. Environmental motivation studies
2. Stimulate and develop tolerance of the various disciplines engaged in a laboratory
3. Develop more sophisticated methods of financial control
4. Develop improved methods for project scheduling and control

The research administrators are presented with a difficult task. This task requires more sophistication in planning and execution than many other areas of human organizational endeavor. So far they have done well.

## REFERENCES


(1) Anthony, Robert N., *Management Controls in Industrial Research Organizations*, Harvard Printing Office, Cambridge, 1952.

(2) Bello, Francis, "The World's Greatest Industrial Laboratory," *Fortune*, 58:149-160 (November 1958).

(3) Furnas, C. C., *Research in Industry, Its Organization and Management*, D. Van Nostrand Company, Inc., New York, 1948.

(4) Hertz, David B., *The Theory and Practice of Industrial Research*, McGraw-Hill Book Company, New York, 1950.

(5) Howard, George W., *Common Sense in Research and Development Management*, Vantage Press, New York, 1955.

(6) Kalson, Norman H., "An Analysis of Techniques for Increasing Creativeness of Engineering Personnel in the Research and Development Laboratories," unpublished MBA Thesis, University of Southern California, Los Angeles, 1956.

(7) Rubel, John H., "Engineering the Engineering Organization," paper presented for the Winter General Meeting of the American Institute of Electrical Engineers, New York, January 1956.

(8) Titley, John H., "Problems in Research Management Affecting an Industrial Organization," unpublished MBA Thesis, University of Southern California, Los Angeles, 1955.

(9) Voorhies, Darrel H., *The Coordination of Motive, Men, and Money in Industrial Research*, Standard Oil Company of California, 1946.

(10) Weschler, Irving R., and Brown, Paula, *Evaluating Research and Development*, Human Relations Research Group, Institute of Industrial Relations, University of California at Los Angeles, 1953.

(11) *The Mighty Force of Research*, by editors of *Fortune*, McGraw-Hill Book Company, New York, 1956.

(12) "Research and Development. Can it Really Pay off for the Small Company?" *Product Engineering*, 29:23-25 (October 6, 1958).

(13) U. S. Department of Labor, Bureau of Labor Statistics, *Preliminary Report on a Survey of Research and Development Costs and Personnel in 1953-1954*, The United States Government Printing Office, 1955.



Now Available to AIIE Members

**AIIE decals**

Approximately 3½ inches in diameter

Cost $.50 for two (minimum order)

Order from: AIIE Headquarters
145 North High Street
Columbus 15, Ohio

# Better Work Standards Through Statistical Time Analysis

## Quality Versus Quantity in Time Study

*by* **SIDNEY SMITH**

*Industrial Consultant, Rath & Strong, Inc., Boston*

THE development of accurate standard times for work measurement involves extensive analysis of variable data. Variations in actual times are caused by differences in operator skill and pace, machine characteristics, and working conditions, quite aside from differences in ability of the observer to level or rate the actual work pace to his concept of "normal." Time study engineers can profit materially by procedures and techniques successfully developed for handling other complex variable sample problems.

For years, statistical engineers have been analyzing all kinds of variable data for such applications as machine capability determination and quality control. Among other approaches, statistical engineers have established practical methods for computing the accuracy of data and for estimating the amount of information needed to attain any desired level of precision. These same techniques can help achieve five goals in standard time data analysis:

1. By quickly indicating deficiencies in watch readings and/or rating ability on the part of the time study staff.
2. By assuring that there are sufficient data to bring results within predetermined limits of accuracy.
3. By helping to indicate whether an element is constant or variable.
4. By making it possible to establish, or "close out" the standard time for an element with a minimum of effort.
5. Finally, these techniques are highly effective in training time study personnel and achieving reliable data at minimum cost.

The purpose of this article is to describe certain statistical techniques and graphic procedures which are based upon three years of research work and have been successfully applied in industry to achieve the above goals.

### THE STATISTICAL TIME ANALYSIS SHEET

One of the tools used is the "Statistical Time Analysis Sheet" (hereafter abbreviated to "STA" sheet), shown in Figure 1. This chart makes possible:

1. Convenient accumulation of raw element time study data.
2. Elimination of a separate multiplication step in normalizing or rating.
3. A visual comparison of the observed times and ratings of each time study man.
4. A visual analysis of accumulated data to make maximum use of all information collected, together with immediate identification of abnormal values.
5. Presentation of the collected data in a statistical distribution to assure that the element has sufficient central tendency to be represented by a single element value.
6. A quick, standardized procedure for obtaining the mean of the normalized time values.
7. Visual demonstration, to both management and labor, of the reduction of the spread of actual times.

The STA sheet is laid out on log-log paper, with actual watch readings on the ordinate, and normalized or adjusted times on the abscissa. Normalizing is done by means of the diagonal lines, of which there is one for each 10% increment of the rating scale. A stopwatch reading is counted off on the vertical scale and carried horizontally to the right to the point of intersection with the diagonal line corresponding to the rating of that watch time. Here the point is entered, usually with a symbol identifying the

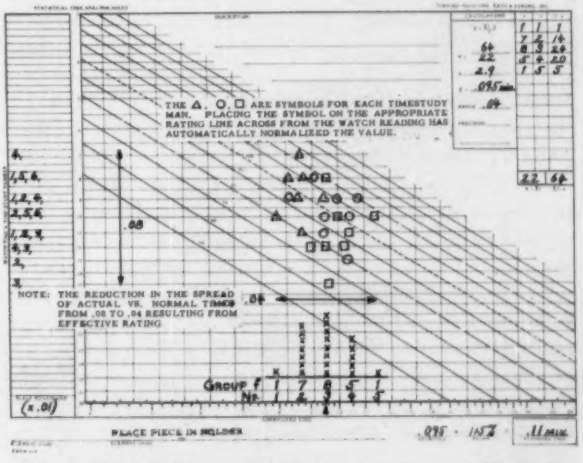

THE Δ, O, □ ARE SYMBOLS FOR EACH TIMESTUDY MAN. PLACING THE SYMBOL ON THE APPROPRIATE RATING LINE ACROSS FROM THE WATCH READING HAS AUTOMATICALLY NORMALIZED THE VALUE.
NOTE: THE REDUCTION IN THE SPREAD OF ACTUAL VS. NORMAL TIMES FROM .08 TO .04 RESULTING FROM EFFECTIVE RATING
.08
.04
GROUP
PLACE PIECE IN HOLDER

FIG. 1. Statistical Time Analysis Plot of a Constant Element.

time study observer. A separate STA sheet is used for recording the data for a single element of work.

Note that the time scales, as in a slide rule, have no fixed decimal, and the values can be chosen to fit any convenient scale. The diagonal lines will apply for any scale chosen. The rating lines in the illustration have been marked off with 100 corresponding to normal effort rating.

Assigning an element number in the lower left-hand of the sheet facilitates finding the sheet for a specific element when the sheets are accumulated in a binder. Since there will be one sheet for each element, there may well be several hundred different sheets for each data category. The numbers of the time study sheets from which the element time and rating were taken are entered in the ruled column to the left, facilitating checking back to source data when required. For most effective analysis, individual watch readings are posted, although averaged times may be used when the data accumulate rapidly.

To show how the normalized times result in a narrower spread than is the case for the watch times, the frequency distribution of the adjusted times has been sketched in on the chart.

## USE OF STA SHEETS IN TRAINING

When trainees simultaneously time and rate several runs of a simple job, their data for each element plotted on the same STA sheet will quickly show up the consistency of their ratings, or lack of it. Since theoretically the watch times and ratings should be identical for all of the men, the watch times for each run should group as should the rating values. Inconsistent watch readings or ratings immediately show up as scattered points, and identify the trainee by symbol.

Comparison of ratings of the same element from one study to another brings out a fundamental advantage of the chart for analysis. If ideal rating or leveling has been applied, the points plotted on an STA sheet must fall in a vertical line. Thus, .20 min. at 100, .16 at 125, and .40 at 50 will plot one above the other, since each one of these must normalize to 0.20 min., read on the horizontal scale.

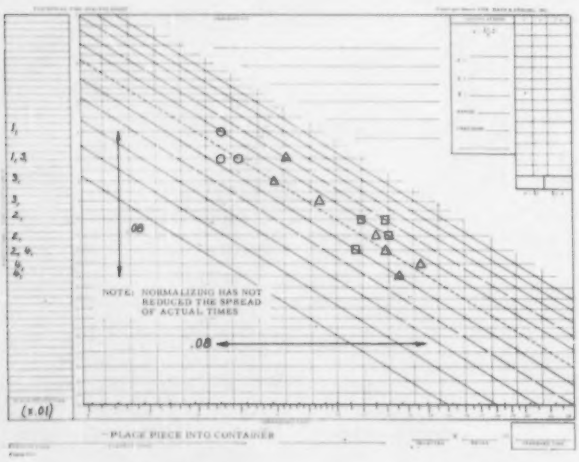



Fig. 2. Statistical Time Analysis Plot of a Variable Element.

Of course, such a vertical straight-line plot would occur only on a perfectly observed constant element. In practice, as the observations are less than perfect, or the element content changes slightly, the plot swells out to an oval, or in other ways departs from the vertical.

As an element takes on variability, the plot veers over to the left, and in the extreme case would form a straight line paralleled with the rating lines. That is, in a completely variable element, even perfect rating will not compensate for the differences in the observed watch times, which are in fact caused by the variability of the element itself, and not by inaccuracies on the part of the observer. Thus, where a seasoned time study man is taking the readings, the STA sheet immediately signals this variable characteristic of the element.

Figure 2 is a plot of a variable element. Figure 3 pictures a bimodal element, where two different conditions or methods have been plotted for a single element. For example; operator A picks up two pieces at a time while operator B handles only one.

The most important point with regard to variation in reading is that the spread of normalized times be significantly less than the spread of actual times. This is a measure of the effectiveness of rating, and should be constantly reviewed.

As a training group develops skill, points plotted on an STA sheet for a given run will begin to bunch together and the bunches will begin to line up vertically. The usual initial errors in rating are easily spotted by the trainees themselves and can thus be more easily corrected.

It has been the practice of the author not to give the trainees any inkling of what the correct rating should be. First, through use of the STA sheet, the group will pull together to a common rating norm—a pattern of vertically plotted points. Second, the norm can be adjusted to provide the earning opportunity desired—by moving the vertical pattern to left or right through the use of rating films and demonstrations. In this way the group learns to conceive of a normal pace as a natural thing, not something they were instructed to achieve, and this results in more confident rating and easier grasping and retention of the concept of "normal."

## USE OF STA SHEETS IN ESTABLISHING ELEMENT STANDARDS

STA sheets make possible the quick and effective analysis of data obtained by trained personnel. Specifically, by use of the sheets and related analyses you can:

1. Make sure that the data are a good, representative sample of what is taking place.
2. Determine that the elements observed are consistent, analyzable, and are not out of control.
3. Maintain the quality and quantity of the data obtained by each observer.

4. Stop collecting data as soon as the desired degree of precision is reached.
5. Close out the element to a fair representative value.
6. Preserve the data for easy reference and maintenance.

Data of a single observer plotted to the STA sheet furnish no positive check on the quality of his readings and ratings. However, when three or more time study men study and plot the same elements, meaningful comparisons of watch times and ratings are quickly made. As in the case of trainees, scattered points can be readily checked to see if they were caused by rating, or were inherent in the watch times. Colors and symbols in plotting show clearly who is getting the most data, and on which elements.

When individual observed values are plotted, the scatter of points can be used to stress vividly the importance of accurate watch reading and rating. Quality is to be emphasized over quantity, as it takes a proportionately greater volume of data to make up for careless observations.

An important part of developing consistent standard element data with a minimum of observations is making sure that the observations cover a sufficiently wide range of the machines, jobs, and personnel to which the standards will ultimately apply. Backstopping on this point can be accomplished by coding the plotted points, indexing time study numbers to facilitate easy reference to operator, machine or job numbers, size, weight, etc., and by similar means. These methods also provide a check as to whether the observers are selecting the easy operations or cooperative operators, or if the data sample is by chance being drawn from a few unrepresentative jobs.

## IMMEDIATE ANALYSIS

A feature of the STA sheets as compared to traditional methods is that the analysis is performed almost immediately after the observations are made. The nature of the element is frequently predictable with as few as five points on a plot. If the times are plotted right after they are taken, the observer can recognize a complex element immediately, and change the end points or look for a variable before more time is wasted. Thus, a horizontal spread, as previously described, is an immediate signal for further analysis.

As a first step, the time studies associated with the extremes of the plot can be analyzed to locate the cause of the variation. The time study numbers recorded in the left column of the STA sheet will simplify this procedure. If a variable element is discovered, it can be re-plotted on a Variable Element STA sheet in relation to the proper scale of the variable, and the number of readings for the required precision can be computed in a manner similar to that described for constant elements. Another procedure for variable elements is arbitrarily to break up the range of the element into steps of the variable, which are logical steps for standards application, and to plot each one of these on a separate STA sheet, treating them as constant elements.

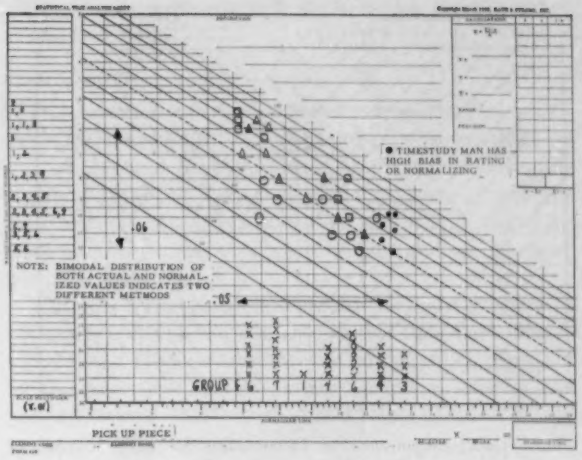

● TIMESTUDY MAN HAS HIGH BIAS IN RATING OR NORMALIZING
.06
NOTE: BIMODAL DISTRIBUTION OF BOTH ACTUAL AND NORMALIZED VALUES INDICATES TWO DIFFERENT METHODS
.05
GROUP
PICK UP PIECE

FIG. 3. Statistical Time Analysis Plot of Bimodal Data.

After brief practice, these steps can be followed by most time study personnel, and require little help of a time study analyst. With the elements straightened out at the start of data collection and signals given when an element begins to be complex, the main body of data can be collected with confidence and with minimum wasted effort.

## PRECISION VALUES

Once the elements have been defined and the variables, if any, isolated, it only remains to collect sufficient data on each element to arrive at a valid representative value for it. This brings up the concept of the degree of precision achieved in terms of the size of the sample, spread in the readings and the like.

The precision or degree of confidence in the average time value selected to represent the data, varies directly with the average value of the data and the number of observations made, and inversely with the spread of the data. An equation can be developed by which precision may be ascertained.

The degree of precision *required* in an element time varies inversely with the degree of tolerance allowed in the computation of the operators' incentive pay. In other words, how well, statistically, does the selected value have to represent the data in order not to throw the operator's earned minutes and pay off by more than a certain desired percentage?

On the bases of the above two values of precision, the amount of data that must be collected on that element can be determined. However, this discussion of the explanation behind the procedure makes this part of the analysis seem much more complex than is actually the case in practice. The computations are simplified by the use of a chart, shown in Figure 4.

The left-hand portion of the chart relates the average

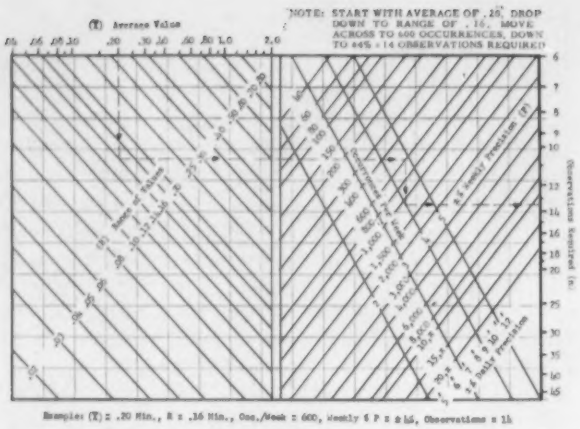

(X) Average Value
NOTE: START WITH AVERAGE OF .20, DROP DOWN TO RANGE OF .16, MOVE ACROSS TO 600 OCCURRENCES, DOWN TO 44% = 14 OBSERVATIONS REQUIRED
Range of Values
Occurrences Required (n)
Example: (X) = .20 Min., R = .16 Min., Occ./Week = 600, Weekly ± P = ±5, Observations = 14

FIG. 4. Computing Chart for Determining Required Number of Time Study Observations.

value of the element time to the range or spread of the individual readings that make up the sample. The graph is so constructed that the range related to the average is equivalent to ± two standard deviations over the average value. (This is approximately equivalent to

$$\text{precision} = \frac{\pm 2\sigma}{\sqrt{n}\,\bar{X}}$$

except that the number of readings has been combined into the computation on the right-hand portion of the chart). The right-hand portion of the chart multiplies the number of occurrences per week into the previous data in such a way that the effect of precision can be related to the importance of this element in the weekly pay. Next drop down to the desired weekly precision and move across to the number of observations required for the desired accuracy. This combines the precision of an individual element by itself and the statistical effect of such precision in a manner comparable to the square root of the sum of the squares. By this method set-up values that may occur infrequently can have far less readings than cycle elements that are of smaller value but repeat continuously.

The broken line at the top of the chart illustrates its use: To determine whether you have taken at least the minimum number of readings ($n$) required to assure a desired degree of precision in the data average, locate the data average ($\bar{X}$) at the left of the upper edge of the chart. Move downward until you reach a diagonal line representing the data range—i.e., the difference between the maximum and minimum value of the data used to obtain the average. Now move horizontally to the right-hand member of the chart, until you reach the diagonal line representative of the expected maximum occurrences per week. (These values are read on the diagonal lines sloping downward to the left.) From this point move vertically to the intersection with the diagonal line (sloping downward to the right) representative of the degree of precision desired. Now move horizontally to the right and read from the vertical scale at the right-hand edge of the chart the minimum number of observations required to reach the stipulated degree of precision.

Obviously, where desired, this computation chart could be used in reverse: From averages obtained by a given number of readings, with a given data range for a given number of expected occurrences per week, the degree of precision to be expected could be ascertained.

Taking at least the minimum number of observations indicated by the chart assures that no element would be so inaccurately measured as to affect the total earned standard minutes by more than a desired precision, usually ± 3% per week. Since the chart gives effect to both the magnitude of the element time and the frequency of its occurrence, its use assures that the work spent collecting data on an element and, hence, the cost is in proportion to the importance of the element. Many elements, because of their small average value and few occurrences per pay period, require only a few observations, usually many less than had been obtained by other procedures, with no loss of desired objectives.

## CLOSING OUT THE STA SHEETS

When enough data have been collected, each STA sheet is closed out to obtain the standard minute value for the element ($\bar{X}$ on the chart). This is conveniently done by averaging the data in groups. The procedure here, which effects a substantial saving of time in computation, is as follows (refer to Figure 1):

Equally spaced vertical lines are drawn to embrace the plotted points. After excluding certain fringe points which are obviously out of line and not to be included in the average, these equal columns are numbered consecutively, as shown on the chart, and these numbers become the values ($x$) as indicated in the box in the upper right-hand corner. Beside each ($x$) is posted the frequency with which plotted points occur in each column. The average value ($\bar{x}$) is obtained as indicated, and read off (slide rule fashion) on the chart's abscissa, to give the average time for the element, or ($\bar{X}$).

If the vertically spaced lines were placed at even time intervals, they would get progressively closer as they proceed to the right. This type of form could have a slight tendency to extend or skew the histogram to the right, which is a frequent occurrence in time study data.

The statistical computation of the average from the evenly spaced form tends to move the average slightly towards the mode cell. The effect of this is so slight that it may be better to delete the statement from the article.

We tried both methods in our original research work and are still using some of the charts with a gradual decreasing cell size that correspond to the units of normalized time.

This final selected value, $(\overline{X})$, is then multiplied by the personal and fatigue factor, giving the standard minutes for the element, which is entered on the sheet. The value for % Precision is obtained from the computing chart. These steps are soon learned by the time study personnel and assure uniform averaging of the collected data. The end result is a notebook full of STA sheets closed out to standard minute values, with the element descriptions generally typed in.

### AUDITING THE STANDARDS

When standards are audited, preferably no less than once every two years, the notebooks of STA sheets again come into use. New time studies are taken and plotted to the sheets. Statistical procedures can be used to determine if the new data could actually have been obtained in the original studies—i.e., to determine if the source of the data has changed in any way. However, inspection of where the new plotted points fall with respect to the old is usually sufficient to indicate which element times should be rebuilt.

### CONCLUSION

This article has described graphic procedures by which statistical techniques can be applied to the analysis of time study data for the more accurate determination of standard times for work measurement. These procedures require fewer actual readings than are usually taken by traditional methods, and lighten the computational chore normally involved.

While STA sheets are no cure-all, they are effective in obtaining more accurate results in less time than is usually taken. They are useful in training work, and are highly popular with time study personnel because the presentation is easily understood, and because of the saving in time and effort which they make possible. In addition, they provide a means for continuously auditing the ability and skill of time study personnel.

# An Application of Queueing Theory for Determining Manpower Requirements for an In-Line Assembly Inspection Department

*by* **LAWRENCE J. SESPANIAK**

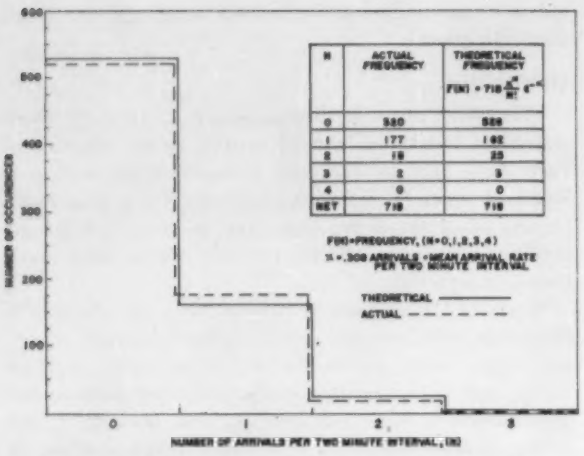
*Industrial Engineer, Pratt & Whitney Aircraft Division, United Aircraft Corporation*

AT Pratt & Whitney Aircraft we are applying queueing theory to resolve a number of Industrial Engineering problems where conventional methods become either too cumbersome or do not tell the whole story. For example, conventional labor standards are frequently applied to a manufacturing schedule to determine manpower requirements. Usually, in converting a manufacturing schedule into manpower requirements, additivity of labor standards is assumed; however, in certain special cases where unavoidable delay or idle time and other factors are part of the day to day operation the assumption of additivity of the labor standard may not be tenable (2). One such operation is the in-line inspection of aircraft jet engines during the course of assembly. This treatise deals specifically with the manner in which queueing theory has been applied to determine the optimum number of inspectors to meet a given engine build schedule by minimizing the sum of the costs of inspector idle time and inspection caused assembly line delays.

### INSPECTION

In-line inspection as used in this paper is defined as an inspection operation which occurs while the product is in process; whereas the conventional inspection function is performed either before or after an operation or part is completed. The in-line assembly floor inspectors at Pratt & Whitney Aircraft are responsible for the condition of parts going into engines and the correct assembly of engine components at two or more assembly work stations manned by from one to four assemblers.

The final assembly of a jet or gas turbine engine is an extremely precise operation with a fairly long work cycle at each assembly station. In addition, the jet engine is built in many different models; and, in general, there is considerable variation in assembly inspection requirements from model to model. During the jet engine build at each assembly station there are certain points in the station cycle at which inspection must occur before additional work or assembly can proceed; these points will be




| N | ACTUAL FREQUENCY | THEORETICAL FREQUENCY $F(N) = 718 \frac{a^N}{N!} e^{-a}$ |
|---|---|---|
| 0 | 320 | 328 |
| 1 | 177 | 182 |
| 2 | 19 | 25 |
| 3 | 2 | 3 |
| 4 | 0 | 0 |
| SET | 718 | 718 |

F(N) = FREQUENCY, (N = 0, 1, 2, 3, 4)
a = .308 ARRIVALS = MEAN ARRIVAL RATE PER TWO MINUTE INTERVAL

FIG. 1. Distribution of Arrivals—Station 1 Final Assembly

called arrivals. Since the in-line assembly inspection is an in-process function of a variable, long-cycle assembly operation, we concluded that inspection arrivals would not occur at fixed intervals but are statistical in nature. We found it convenient in gathering data to use a wrist watch to record arrivals of inspection and a stop watch to measure the duration of the inspection time which included any walking time to the point of inspection.

## INSPECTION DATA

Our data on arrivals for inspection at one assembly station are tabulated and plotted in Figure 1. The selection of a two minute interval is a matter of convenience. We fitted a Poisson distribution to the data and used the chi squared goodness of fit test as an acceptance criterion. The goodness of fit test indicated that the actual distribution of arrivals could be approximated by the Poisson distribution. The above analysis was followed for each assembly station studied.

The distribution of inspection times is tabulated and plotted in Figure 2 with an exponential function fitted to the data. Again using the chi squared goodness of fit test as a decision criterion, the distribution of inspection times was assumed exponential. The nature of assembly operations resulted in several different groups of inspection times.

In collecting data we observed that the selection for inspection was not "first-come, first-served" as originally anticipated. For example, if two arrivals for inspection occurred at approximately the same time, the inspector would generally answer the nearest call first. We, therefore, assumed that the selection for inspection was essentially random.

## QUEUEING MODEL

The queueing model used in "A Congestion Problem" by Georges Brigham fit the conditions we found common to the in-line assembly inspectors (1). The assumptions are Poisson arrival distribution, exponential inspection time distribution, and random selection for inspection. The data in Figure 1 and Figure 2 and the chi squared test support the assumption of the Poisson distribution for arrivals and the exponential distribution for inspection times. Actual observations indicated that selection for inspection was essentially random.

Notation:

$a$ = number of arrivals per mean inspection time
$c$ = number of inspectors
$r_a$ = cost of delaying the assembly station per unit time
$r_c$ = cost of idle time for the inspector per unit time
$r = r_a/r_c$ = ratio of the costs of times
$P$ = probability of an assembly station being delayed

$$P = \frac{a^c}{(c-1)!(c-a)}\left[1 + \frac{a}{1!} + \frac{a^2}{2!} + \cdots + \frac{a^{c-1}}{(c-1)!} + \frac{a^c}{(c-1)!(c-a)}\right]^{-1}$$

where $c > a$

$C'$ = "normalized" cost

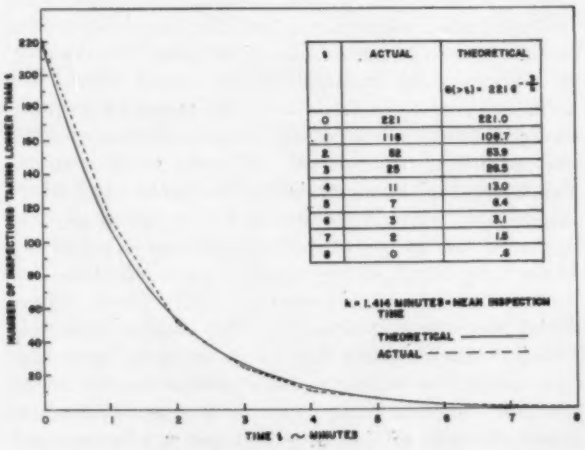
$$C' = (c-a) + \frac{raP}{(c-a)} \qquad \text{Eq. 1.}$$

We found that the curves for Eq. 1 given in Brigham's "Congestion Problem" did not encompass sufficient inspection or servicing units to meet our requirements. With the aid of an I.B.M. 701, we plotted Eq. 1 for an extended number of inspectors or servicing units.

## DETERMINING NUMBER OF INSPECTORS

To calculate the number of inspectors for a given engine build schedule, engine requirements must be converted into the average number of arrivals per mean inspection time $a$, and the ratio of the costs of times $r$ must be calculated.

For each engine there is a build sheet composed of a




| t | ACTUAL | THEORETICAL $\Phi(>t) = 221\, e^{-\frac{t}{1.4}}$ |
|---|---|---|
| 0 | 221 | 221.0 |
| 1 | 116 | 109.7 |
| 2 | 52 | 53.9 |
| 3 | 25 | 26.5 |
| 4 | 11 | 13.0 |
| 5 | 7 | 6.4 |
| 6 | 3 | 3.1 |
| 7 | 2 | 1.5 |
| 8 | 0 | .8 |

FIG. 2. Distribution of Inspection Times—Station 1 Final Assembly

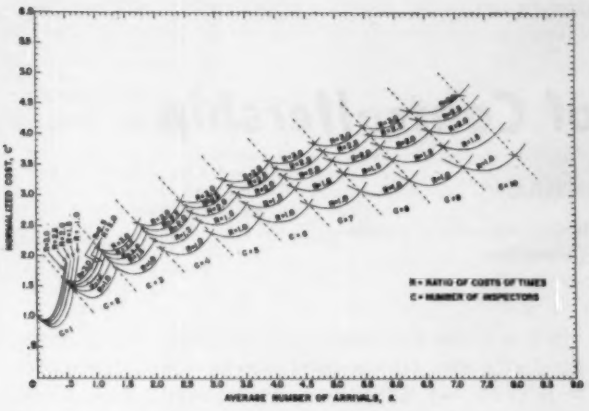



FIG. 3. Normalized, Total Cost of Waiting Times, $C'$ as a Function of Average Number of Arrivals Per Mean Inspection Time, $a$

number of assembly and inspection sequences which must be signed out by the assembler and inspector respectively. For each sequence on the build sheet there may be one or more inspections. We found that the number of inspection sequences on the build sheet did not equal the number of actual inspections. For example, a bearing might have two inspections, an inspection both before and after assembly, but only one inspection sequence. In addition there is some reinspection. To overcome these difficulties, we resorted to sampling to ascertain the number of inspections per sequence. The character of the assembly operation made the use of several different inspections-per-sequence ratios mandatory.

The product of the inspections-per-sequence ratio and the number of sequences for any particular engine type equals the number of inspections for that engine. For example, if an engine has 200 inspection sequences, and has 2.4 inspections per sequence on the average, then the average number of inspections on that particular engine type would be $200 \times 2.4$ or 480 inspections. Following the above technique for all engine types an expected number of inspections per day can be easily calculated based on the engine build schedule. Finally multiplying the expected number of inspections per day by the mean inspection time and dividing by the working time per day, the average number of arrivals per mean inspection time can be calculated. The above is a simplified representation of the procedure followed in our calculations for the average number of arrivals per mean inspection time; a detailed account of our procedure would require merely the inclusion in the calculations of several inspections per sequence ratios and several mean inspection times.

Once the average number of arrivals per mean inspection time and the appropriate ratio of the costs of times is known, the number of inspectors to meet a given engine build schedule can be easily determined from Figure 3. To use Figure 3 select the family of curves with the appropriate ratio of the costs of times. Find the average number of arrivals per mean inspection time $a$ on the horizontal or x-axis and project a line vertically to the appropriate ratio of the costs of times curve. Read the "$c$" number between the oblique dash lines. The "$c$" number is the optimum number of inspectors for the calculated average number of arrivals per mean inspection time $a$, and the ratio of the costs of times $r$. We use the foregoing method not only to forecast inspection manpower requirements, but also to evaluate inspection performance on our weekly Inspection Labor Performance Report.

Our calculations give the manpower requirements for (say) an entire assembly line. Overlapping multiple station assignments based on equal inspector work loads are estimated for each inspector, rather than assigning a group of inspectors to an entire assembly line.

## CONCLUSIONS

It is obvious that there are many other service activities to which a queueing theory approach can be applied to determine manpower requirements. Some areas of possible application are test inspection, Quality Review Cribs, many inspection crib activities, inside and outside trucking, shipping and receiving, and maintenance and repair. In addition, we have used queueing theory to resolve a number of other operating problems; for example, the determination of hoist requirements for the die making department.

## REFERENCES

(1) BRIGHAM, GEORGES, "A Congestion Problem," *Journal of the Operations Research Society of America*, November 1955, pp. 412-428.

(2) FELLER, W., *An Introduction to Probability Theory and Its Applications*, Wiley, New York, 1950.

INDUSTRIAL ENGINEERS

Large synthetic fiber producer has attractive openings in its Industrial Engineering Department for recent engineering graduates or men with one to three years industrial engineering experience to be trained for participation in a complete and well rounded Industrial Engineering program.

Pleasant working and living location in Western North Carolina or Eastern Tennessee near Asheville, North Carolina. Excellent benefits: five-day week; moving expense. Send complete resume, including salary requirements, to Employment Manager, Enka, North Carolina.

AMERICAN ENKA CORPORATION
Manufacturers of Rayon and Nylon

# The Organization of Controllership

by E. B. COCHRAN*

*Manager, Planning Department, Wright Aeronautical Division, Curtiss-Wright Corporation*

*In the natural development of the Industrial Engineering function within many organizations, the Industrial Engineer has assumed many responsibilities of a "controllership" nature. This progression is a natural one, and one that is likely to continue at an accelerated pace as the Industrial Engineer becomes more proficient with the newer concepts and techniques associated with his field. It is with this thought in mind that we have selected this article for publication. The alert Industrial Engineer will be aware of the contributions that he may be able to make in the pursuit of the "controllership" function, even though he may be inclined to assume that the function is one of Industrial Engineering rather than of controllership. There is small profit in arguing titles.*

*It should be noted that the author does not present a modern view of Industrial Engineering. He confines the Industrial Engineering function to shop and manufacturing activity, and does not recognize the emerging role of Industrial Engineering as an engineer for management—dealing with the systems analysis and design of broad management problems.*—ED.

THE controller's function in the enterprise is undergoing considerable change in the direction of becoming the chief planning and control officer for the enterprise (1). But at present there is frequent misunderstanding of, and lack of sympathy toward, the controller's new role by other executives. This is partly due to fuzzy or outmoded organization theory. But the profession itself can be seriously called to task, since many of those in the position of controller have relied on, and have been trained in, an outmoded and narrow conception of their responsibility. Often this lack of breadth is given protective coloration by verbal obeisance to "modern" controllers' "code," such as the very good one issued by the Controller's Institute.

The powerful need of the enterprise for broader controllership arises from three primary sources:

1. The growing size and complexity of the individual business enterprise.
2. The resulting multiplication of specialists at both the technical and executive levels, with consequent difficulties of coordination and dilution of executive interest in maximizing profits.
3. The trend toward applying the formal planning and control technique, aimed at achieving carefully determined profit objectives, which places intense administrative and analytical loads on top management.

The controller is the natural organization position in which to center the coordination effort now widely recognized as a must for sustained success of the larger enterprise (with, say, $20 million or more sales a year). Consequently his duties may be enunciated broadly under three main headings as follows:

*Planning*

Supervises the preparation of company short and long-range plans, approving all measures of activity and cost standards contained in them.

Evaluates the company's master plan of operation and investment and recommends action to top management.

*Follow-up*

Conducts follow-up activity to determine areas of poor performance against the plan and to insure that corrective action is being taken.

*Measurement*

Supervises statistical activities necessary to properly report on actual and planned activity, and issues financial statements and related data to all requiring them.

Further detail will be found in the job description provided in Figure 1.

This is certainly a somewhat ambitious set of duties. Therefore this paper will describe in further detail the organization required by a controller who is to perform such tasks.

## GENERAL PATTERN OF THE CORPORATE ORGANIZATION

There are, of course, a number of basic approaches to the formal organization of any particular enterprise. Each reflects requirements defined by the industry in which the company operates, its choice of products on which it chooses to compete, the size and location of facilities operated by the company, the particular skills and limitations of the management itself, and so on. Each approach will strongly affect the controller's organization since it will establish the departmental breakdown and interrelations which are the very fabric of any planning and control program to be administered by the controller.

Therefore for the sake of definitness we shall first take one basic pattern of over-all organization as a framework for this discussion: that of the ordinary medium-sized centralized manufacturing company. With a full complement of normal marketing and product design problems, its manufacturing does not yet involve the organi-

* Currently Budget Manager, Rohr Aircraft Corporation.

JOB DESCRIPTION: CONTROLLER

REPORTS TO: The president

BASIC FUNCTION:

To assist the president and his principal executives to obtain maximum profits; spearheads the joint development of realistic operating and investment plans and standards, and administers a system of positive follow-up and controls.

SUPERVISES:

Manager of Controls and Analysis
Manager of Industrial Statistics
Manager of Cost Analysis
Manager of Cost Accounting
Manager of General Accounting
Manager of Procedures and Audits

SPECIFIC DUTIES:

*Planning*

1. Develops and publishes the ground rules for company short and long-range planning and the general procedure to be followed by each function. Works with department heads to coordinate their planning with company policies and objectives.
2. Reviews and clears all cost standards and measures of activity proposed by departments for use in plans and budgets. Initiates studies of areas where measures are not felt to be reliable.
3. Combines the proposed plans of all departments. Appraises the effects on profit, financial and market position, and the progress anticipated. Evaluates the realism of the proposed plan against general business and industry conditions. Summarizes points of importance for the president and recommends action on the master plan of operations and investment.
4. Issues monthly projections of current operating results for several months ahead, relating changes to the original plan.

*Follow-up*

5. Develops and insures timely issuance of control reports to the president and his principal executives. Administers a system of supporting reports to underlying levels of supervision.
6. Performs periodic review and appraisal of operations, involving study of performance in all operating areas and determination of factors underlying poor or good results.
7. Conducts a monthly review meeting with the president to bring out significant operating results and action points. Assists the president to prepare for his own follow-up meetings with key operating executives.
8. Works with all levels of supervision to develop understanding of quotas and budgets, the use of control reports, and the technique of holding review meetings on their own performance.

*Other*

9. Reviews major pricing proposals for maximum profitability and thorough analysis of volume effect.
10. Conducts general accounting, cost estimating, cost accounting, and payroll activities, insuring adequate control over sources of basic data and conformance with government contract requirements. Issues necessary statements, reports, and special statistics.
11. Coordinates the development of, and publishes, all inter-departmental procedures and all manuals and procedures with control significance; audits conformance to such procedures and manuals. Initiates steps to simplify procedures and cut costs.
12. Administers a reports control system covering all recurring reports in the company.

FIG. 1

zation complexity which accompanies the existence of several sizable and scattered major facilities. A brief organization chart is provided in Figure 2, with major departmental breakdowns indicated for later reference.

It will be noted that the treasury function is shown as separate from the controller. This is not an essential condition since the two easily may be combined, as under a vice president-finance. The choice to be made here is largely one of individual preference, the emphasis necessary on financing matters, and the qualifications and interests within the top management group itself.

Later, the application of this approach to decentralized organizations will be discussed.

## DEPARTMENTS IN THE CONTROLLER'S OFFICE

The controller's group divides itself naturally into three classes, corresponding to main areas of the controller's duties. First will come those who operate predominantly in the planning and follow-up areas. Referring to Figure 2 this covers the Controls and Analysis and Cost Analysis Departments. Second are the groups which supply the data, statistics and reports necessary to plan operations, measure results and determine the corrective action needed; this covers Industrial Statistics, Cost Accounting and General Accounting. Third are groups which may be related to one or the other of these two, but which specialize more deeply in one particular phase. In this case there is only one—Procedures and Audit—but there could be others (such as a tax department).

It may we well to call attention to a key principle of the controller's organization: the consistent joining of planning and follow-up functions. Where a department coordinates planning for an area of operations it also should perform the follow-up activity on that area's performance. The need for this unity is inherent. Planning requires before its completion a reasonably close familiarity with the activity, time and ability to analyze it, effective communication with the line personnel involved (who after all must generate the plans themselves in terms of sound practice or growth), and a capacity to re-

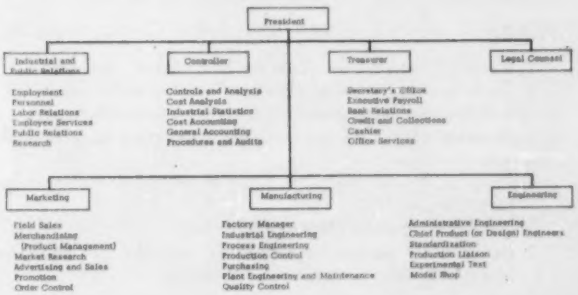



FIG. 2. Summary Organization Chart of a Non-Decentralized Manufacturing Company.

late each operating area to the others. Follow-up requires exactly the same background and abilities, plus intimate familiarity with the analysis and negotiation which accompanied the submission and approval of operating plans. The two functions therefore must be discharged by the same group for a given area of operations.

Another principle is worth reference here. That is, the separation of statistical from planning and follow-up duties. In many organizations there are several groups within the controller's department which combine these; often a "budget department" is also a central statistical agency, or general accounting prepares company forecasts from the ground up. Such practices often are a necessary interim step towards a sound program of planning and control. But if continued for long they can cause dilution of effort and a poor fit between the tasks to be done and the personnel used on them. The psychology of the two is quite different, and it is dangerous to combine them too closely.

### CONTROLS AND ANALYSIS DEPARTMENT

The functions of this department—or some portion of them—may be found residing in groups with a variety of names: "budget department," "statistical control," "planning office," "administrative department," are a few. The important thing is that the functions be performed in an efficient and economical manner. This cannot be the case where they are considered as mere personal duties of the controller himsef.

If the controller's office is to contribute as it can to company profits it requires a well-knit group of able, aggressive, imaginative, analytical people. These people must be able to think broadly—as broadly as top management itself—for their assignment is nothing less than to spearhead the profit search which is management's prime objective. The group is responsible for establishment of sound planning procedure, careful evaluation of plans, effective follow-up reports, penetrating analysis of results and a continual training of other departments in the attitudes and action of profit improvement. These responsibilities therefore require isolation from routine and constant exposure to top-level problems and policies.

The department's duties may be more specifically listed as follows:

*Planning*

1. Recommends over-all planning and control procedures.
2. Issues necessary ground rules and instructions for planning.
3. Assists department heads to prepare plans and forecasts.
4. Analyzes plans and forecasts to locate weak spots and obtain correction.
5. Presents over-all corrected plans to controller and management for approval.
6. Publishes approved plans and forecasts.
7. Reviews all capital appropriation requests for soundness and conformance with company programs.

*Follow-up*

1. Establishes control reports to all levels of management.
2. Reviews operating performance against plans and forecasts with department heads.
3. Prepares periodic analysis of results, and presents to the controller and management.

*Other*

1. Reviews major pricing proposals for maximum profitability and through analysis of volume effect.

It should be apparent that this group cannot be saddled with the more routine and detailed tasks of statistical work and preparation of standardized reports if it is to perform at its most effective level. For the same reason it should also be freed from the relatively straight-forward portion of the task of reviewing results against the plans and other measures established. Once the elements of planning and follow-up procedure are established, other departments (such as cost analysis) can take over a sizable share of the review and follow-up of detailed factory operations, for example.

Accounting groups (general and cost) should therefore service the controls group with financial and operating statements, special tabulations and extensive or detailed calculations as required. The cost analysis group should perform preliminary screening and analysis of detailed operation, product and overhead costs against plans and standards, and pass along only major problems for the deeper analysis and recommendations of the controls group. Cost Analysis may similarly review departmental manpower and expense requisitions against approved budgets, referring tough ones to the controls group, and handle the endless review and clearance of new factory cost standards in accordance with the general criteria established by Controls.

Hard and fast rules cannot be stated; the exact delineation of duties will always depend somewhat on the relative strength of the personalities, intellect and experience of the staff comprising each department of the Controller's office. But some such division of duties is essential if the full range of activities is to be handled thoroughly and economically without bogging down the controls group.

Organization of the controls group is again dependent on many factors: size of the company; relative importance of the problems faced by the functional areas of marketing, purchasing, manufacturing and inventory control, etc.; relative strength of departments outside the Controller's office which deal with planning and control matters in their own areas; strengths, weaknesses and human relations of the personnel currently in the controls office; and so forth. However a basic pattern of organization is useful in most situations and forms a rough yardstick against which alternatives may be measured or at least discussed.

Some five sections or activities are fundamentally involved in the successful functioning of a controls group. Due to their critical importance to the Controller's effectiveness each will be discussed briefly.

1. *Operations Analysis* is in a sense the budgetary control group covering operating activities and their costs. This section coordinates the preparation of annual operating budgets and current forecasts to meet company financial objectives as quickly as possible. It establishes keystones of basic budgeting and forecasting procedure and supervises indoctrination and training programs for operating supervision. It reviews budgets and forecasts of cost and investment in detail and recommends approval or other action. It analyzes details of performance and recommends corrective action where possible. It establishes control reports to operating supervisors and conducts performance reviews with them. Emphasis is on improving product and departmental *cost* matters with some attention to related use of inventory and facilities investment; relations with Cost Analysis are close as will be seen later.
2. *Product Performance Analysis*, usually a much smaller group, concentrates on the sales side of company performance. It is essential for good profit control that long and short-range product plans be analyzed thoroughly for their sales volume and profit effects. The Controller must be in a position quickly to point out fallacies in future plans, relating them to past experience, general industry conditions, profit yield, etc. In this connection the section would review proposed production schedules and sales forecasts. It would also watch sales performance against budgeted volumes, market penetration and product mix, passing along its conclusions to other sections of the Controls Department. Where warranted it would keep a watchful eye over the progress of major new product development programs, insuring that delays or early completion are reflected in financial forecasts and that clear explanations are obtained and corrective action recommended.

   Obviously the work of such a group would have close relations with that of Market Research, Production Control and the company economist if there is one. Its justification lies in its interest in the profit consideration and in the development and meeting of product plans which permit the attainment of company budgets and forecasts.
3. *Pricing Analysis* plays a major role in the company's profit control program. This is an area where small apparent differences have major and very tangible consequences in the cash box. The job is a sophisticated one, requiring not only the establishment of sound procedures for drawing up cost studies but also the profit-wise evaluation of major price proposals.

   Many companies fall into the trap of considering pricing to be simply a matter of sales volume or of "cost plus." Both approaches are wrong. The answer lies more in a careful (although not easy) analysis of product specifications, variable, fixed and sunk costs, and profit versus volume relationships—along with the more intangible marketing factors of customer acceptance, effective of promotional programs, re-styling, etc. This section by no means usurps the prerogatives of an analytically minded marketing department, where one exists. It simply meets it halfway, applying the cold criterion of profit results and insuring that the best use is made of data available to measure the true profit of pricing proposals and policies. Many companies would see their pricing completely transformed by such a group in the Controller's office.
4. *Capital Investment Analysis* handles the detailed review of capital investment proposals and analyzes their subsequent results. The benefits of good sales forecasting, pricing and operating cost control easily can be lost through uneconomic facilities. Or what appeared to be sound investments, and perhaps were, may be turned into veritable ratholes for capital funds as expenditures pile up far beyond the approval level or cost reductions fail to materialize. This section obviously must establish the format and supporting detail required for proposals, as well as the type of follow-up reports to be prepared.

   The personnel involved here should have some acquaintance with manufacturing problems and approaches, for it must work closely with production and Industrial Engineers if it is to have its proper influence. Their financial bent and access to forward plans and cost targets within the Controller's office may often lead them to stimulate new facilities programs from Manufacturing and others. Again, if the section is on top of its job, annual preparation of the forward plan for capital investment (which should cover at least five years) should involve simply a summary of programs approved, under active consideration, and known to be required.
5. *Financial Analysis*, in a real sense, has the last word in appraising company performance and helping to formulate programs. For its basic task is the evaluation of results and establishment of goals from the standpoint of maximizing return on capital. This return goal comprises the margin on sales (therefore pricing policy and cost control) and the use of capital (therefore facilities investments and use of working capital items). The group may be small relative to Operations Analysis or Capital Investment Analysis, but its task is large.

   It will prepare studies of competitors and similar companies to develop realistic standards for sales margin, use of capital components such as plant, cash, inventory, receivables, etc., and return on capital employed, for use in budgets and forecasts. It will analyze over-all operating and investment results periodically, using the results of analysis by the other sections, to measure progress toward over-all financial objectives and locate weaknesses in current-operations. It will apply the same approach to proposed budgets and forecasts. It will inevitably become the "special project" section of the Controller's office. It probably will also inherit the task of preparing periodic over-all presentations to management on operating results and progress toward broad financial goals.

The key personnel, and even the junior analysts, chosen for the assignments described obviously do not grow on trees. They must have a considerable background in business and economic theory, plus significant experience in work requiring analysis and evaluation of top-level policies and problems. Personal characteristics are just as important. These people must be initiative if they are to ferret out the problems inherent in proposed plans and policies of current operations, or to devise procedures to implement broad management objectives and policies. They must be flexible—broad background and diversity or experience is better than intense training in a narrow area. They must handle people well—their assignments go deep into the plans, professional hopes and personal pride of the company's key personnel. They must be top-notch salesmen to present their conclusions to management in distilled yet interesting and understandable form.

The likelihood that the accounting profession will supply adequate candidates for this activity is quite small.

### COST ANALYSIS DEPARTMENT

The functions of the cost analysis department are sometimes hidden within a "budget department," or deep

within cost accounting proper. Often they do not appear at all in the Controller's office but are performed entirely in the plant, as by an Industrial Engineering group.

Any of these situations have real disadvantages. In the first instance there is over-burdening of the budget or Controls group, or dilution of its attention to the really crucial and major problems of profit improvement. In the second case there is a strong tendency to be absorbed by the statistical and reporting activities of cost accounting proper, rather than to stay geared to the cost control aspects of the business and keep close to operating personnel. In the third case, there cannot be the objective and thorough review of cost performance details and operating cost standards only possible when a strong Industrial Engineering activity is supplemented, cross-checked and coordinated with management goals by an informed group of cost analysts with primary allegiance to the over-riding importance of financial consequences.

The duties of the Cost Analysis Department may be listed briefly as follows:

*Planning*

1. Prepares and issues indexes of past and future cost levels.
2. Helps establish all manfacturing and material cost standards, including variable overhead budgets.
3. Approves all proposed factory cost standards and changes to them.
4. Coordinates preparation of cost estimates and quotations.
5. Reviews appropriation requests, major purchase requisitions and work orders before issuance to insure accuracy, completeness of data and conformance with established procedures.

*Follow-up*

1. Analyzes variances against cost standards.
2. Evaluates accuracy of factory cost standards.
3. Reviews cost performance with manufacturing and purchasing personnel.
4. Reports actual versus projected savings on capital outlays.

*Other*

1. Recommends procedures for cost estimating and development of standards.
2. Reviews major cost entries.

The best exposition of this department's activities probably is in terms of its relations to other units in the Controller's office and the company.

In relation to Cost Accounting proper, Cost Analysis will prepare special cost statements and analyses from the regular cost data turned out by Cost Accounting. It will also provide Cost Accounting with necessary cost standards for use in variance statements.

In relation to the Operations Analysis Section of the Controls Department, Cost Analysis will locate and summarize all variances against product cost standards and departmental budgets and perform further detailed analysis of cost variances as requested. It will tabulate and review purchase requisitions and proposed work orders against pertinent budgets to insure "pre-control" of expenditures, notifying Operations Analysis of off-standard conditions. It will also evaluate and approve all proposed factory cost standards and changes to them as submitted by Industrial Engineering, insuring conformance with the policies established by Operations Analysis, and it will coordinate preparation of detailed material cost standards.

In relation to the Pricing Section it prepares an index or indexes of past and future cost levels and coordinates the preparation of cost studies necessary for pricing decisions. For Capital Investment Analysis it reviews appropriation requests for accuracy and suitable detail of cost data, and screens work orders for conformance with approved requests.

Organization of Cost Analysis may be handled by about four main sections:

1. A section to develop operating cost standards and review performance against them. (This may, if warranted, be broken down into separate groups for direct labor, factory overhead, tooling and material handling or warehousing.)
2. A section to perform a similar function for material costs.
3. A cost estimating section, to coordinate preparation of estimates, apply rates and review the results.
4. A special studies group to handle the multitude of special assignments, analyses, preparation of cost procedures, etc.

The key people and creative juniors of this department, as in the case of the controls group, must be chosen to a definite pattern. This pattern is in sharp contrast with that normally presented by cost people. But it is essential to achieve it, for upon this rock many efforts to build modern controllership founder: the usual function of "cost analysis" is quite different from that actually performed by many existing groups with the name, and cannot be handled by the personnel at hand.

Good cost analysis people are a special breed. On the one hand they must obviously know a fair amount about approaches to acounting for costs. But more important, they must be operations-minded, interested in shop and field activities and able to speak the language and understand the thoughts and needs of line personnel. Their systems, techniques and analyses must then be geared to an objective of real service, while guided by principles of sound economics in the light of the profit objective. Men who are trained as Industrial Engineers are well-suited for this work. Smart ones will learn all the cost accounting needed, that they don't already know instinctively, within a very short time. In contrast, it is practically impossible to train an old line cost *accountant* to be a good cost *analyst*.

INDUSTRIAL STATISTICS DEPARTMENT

This is a function which can vary in importance and stature from a small "chart department" to a full-blown economic analysis group. The latter is probably the most desirable, since the Controller's office is then supplied with a breadth of outlook most helpful to its financial

analysis of business decisions and results. Let us list certain major duties:

*Planning*

1. Projects long-range industry conditions and company market penetration.
2. Reviews details of forecast to insure reasonableness in the light of industry conditions and trends.

*Follow-up*

1. Reviews company sales results against industry.

*Statistical*

1. Gathers data on company unit production, sales and prices.
2. Gathers data on industry unit production, sales and prices, and on pertinent economic trends.
3. Gathers data on competitors' financial results and investment.
4. May develop price-volume curves on specific products.

The department might in a smaller organization be combined with the Product Performance section of the Controls Department. But if practical it should be separated so as to keep a fairly abstract view of the economics of the company's industry. Its functions take on critical importance for companies operating in several industrial areas, when close analysis of numerous broader economic factors and trends may spell the difference between failure and prosperity.

The department's responsibilities should not conflict with those of market research. There will be areas of overlap, as is the case for many other pairs of departments, but their emphasis is quite different. The one is interested in the economy and the industry as a whole, the other is concerned with interpreting general conditions in terms of specific product proposals and sales programs.

COST AND GENERAL ACCOUNTING DEPARTMENTS

We now come to two pure accounting groups, which have been purposely separated from the more analytical activities. This is not to say that they are completely insulated from all the considerations discussed for their work will be strongly influenced by the requirements of the departments previously described. Their personnel should therefore have some understanding of those requirements and the flexibility to meet them without completely upsetting the routine of statements. A listing of duties follows:

*Cost Accounting Department*

*Planning*

1. Prepares statements pertinent to cost forecasts and budgets.

*Statistical*

1. Records costs by product, process and department, as required.
2. Prepares cost of sales statements.
3. Prepares statements of cost variances.
4. Prepares special cost tabulations as required.

*Other*

1. Recommends improved cost accounting procedures.
2. Manages the taking of physical inventories.

Many details of cost accounting activity have already been touched on and will not be discussed further here.

*General Accounting Department*

*Statistical*

1. Records data in the general books of account, covering fixed assets, working capital, sales and profit.
2. Issues financial statements and government reports.
3. Prepares special tabulations as required.
4. Bills customers and pays suppliers as directed.
5. Prepares payroll.
6. Reconciles bank balances.
7. Keeps property records.

*Planning*

1. Prepares and keeps current material for a comprehensive chart and manual of accounts.
2. Prepares statements pertinent to general financial forecasts and budgets.

*Other*

1. Recommends improved accounting procedures and internal control practices.

To many experts in the financial field it may appear that we have grossly underplayed the contribution and the stature of these two accounting groups. For example, the bulk of discussion to date has concerned the planning and analysis groups. After all, the entire function of Controller started from the requirements and uses of general accounting, while cost accountants have developed many techniques of cost control. Furthermore, it may look as if we are writing off the basic importance of accurate records to a company, and the inherent control exercised by them.

Let this be fully granted. And with it let us point out that the bulk of personnel in the Controller's office will be in these two Departments. But let us not let historical development and the *sine qua non* of accurate records keep us from recognizing the roles which are now pertinent to Controllership and needed by top management.

These accounting groups are logically *service* functions, pure and simple. In fact, they usually need considerable re-orienting to be effective in this respect, given the stepped up pace required by a modern control program. It is difficult to change the approach of a long-established group from a self-centered satisfaction with accurate statements as such, to a real concern that these are timely, readable and designed to supply the data that line people really need.

A certain amount of resentment and antagonism is normal during the transition, and not all the "regulars" will make it. The tension may be especially acute in relation to the needs of the controls and cost analysis functions, for the contrast in function between the accounting activity and these two groups awakens a keen

sense of the loss of relative status which has occurred, and sometimes a difference in pay scales brings this home. Valuable time can be lost, and valuable men too, if the handling is not skillful and insight into the real potential of each man in accounting activities is less than keen. But the company, which allows sentiment about the change-over to affect its speed of action, is losing far more in profits than it would care to calculate. It must not falter.

In fact, something is gained by the separation, even by those who like it least. For the specialist, accounting, as such, will always offer a pretty wide scope of activities and interests. Accountants are now free to do their job of accounting, with the bulk of special projects and upsetting analysis jobs siphoned off in other directions.

### PROCEDURES AND AUDIT DEPARTMENT

Any procedures and audit group is the somewhat unfortunate heir to two absolutely opposed business traditions.

The first involves the need for detailed control over data incorporated into the books of account. Emphasis is on whether bank statements reconcile with receipts and disbursements, whether recorded inventories are really there, whether the books balance and errors are tracked down, etc. This essential and useful function naturally has given rise to the need for detailed prescription of accounting methods and crosschecks, designed to be as nearly foolproof as possible. The nature of accounting procedure however, is such that these procedures must affect activities in many operating departments such as purchasing, material control and sales. In the course of this, auditors and procedures men frequently may point out obvious simplifications in line operating procedures, often being the only group in a company which looks at detailed methods of operation from a relatively impartial viewpoint. However, in many companies operating personnel have complained that the view of the auditors and procedure writers is narrow and guided more by bookkeeping considerations than by the aim of efficient practical operations. Conflicts between the two points of view are of long standing and considerable bitterness.

The second approach to procedures has been of an entirely different sort. It involves the establishment of a special office or unit at a high level in the organization to review and analyze internal operations from the viewpoint of over-all company efficiency. Since the days of Taylor, the need for such a group has had recurring attention. It has appeared in every conceivable organization spot: the president's office; as part of an Industrial Engineering or methods department in manufacturing; as part of an administrative vice president's function; as part of an expanded auditing department; in a department of organization; and so on. The variety of approaches has unavoidably caused confusion as to where such a function should be placed and what separates it from the operating departments whose procedures it affects.

The concept of controllership expounded here carries with it a reasonably clear solution to these conflicting points of view. On the one hand there are many facets of operations which directly affect the books of account and which must be guided by the requirements for accounting control and preservation of assets. This, naturally, calls for Controller's approval and audit of basic procedures. On the other hand, the Controller's new responsibility for profit planning and control requires him to prepare and keep current a sizable amount of procedural material on that topic, so that the many complex tasks involved may be performed in an orderly manner. As a matter of fact, in a developing installation of planning and control technique it will be found that a large share of time by accounting and analytical personnel (and the Controller himself) is on procedural development and discussion. Furthermore, the breadth of this control responsibility will strongly influence the entire procedures activity in the direction of broadening it. This naturally improves the working relationship with line personnel immeasurably. The two approaches to procedures and audits, therefore, may be combined into one as a natural development of the control function, with considerable reduction in conflict and better integration of effort all around. If this is *not* done, the program of planning and control is seriously weakened.

Certain basic points characterize successful operation of a procedures and audit group in this pattern of controllership:

1. Procedures prepared, issued and audited are limited to those with inter-departmental effects or with general planning and control significance. Procedures incident to ordinary internal operation of operating departments do not come within this group's cognizance. After all, a prime factor in supervising a department is to establish sound efficient modes of operation, which are nothing but procedures. And it is essential that line responsibilities not be interfered with. This does not, of course, preclude the possibility of a line department asking for procedures counsel from the Controller.
2. To the fullest extent possible, the procedures group does not "write the procedures." It may point out the need for a new one or revision of an old one, but the procedure itself should be drafted in the first instance by the operating department or departments most involved. This approach has many advantages: it insures close attention to the needs of line executives; it harnesses their attention and backing for the procedures as nothing else can; it improves their knowledge and understanding of their own operations and of their connections with other departments; it avoids the build-up of an extensive procedures staff. In short, it recognizes the basic part played by procedures in all managerial activity and encourages better understanding and use of them by line management.

   Naturally the procedures group must review, collate and coordinate a proposed procedure. This may end in major changes in order to fit needs not perceived or understood by the line department heads. But every effort should be

made to provide for full participation from the ground up.

3. The activity of auditing is broadened to include review of the degree to which *all* major procedures are working out in practice or being adhered to by line personnel. This is not a constant detailed review, but a periodic check for each major procedure. To insure objectivity, it should be performed by personnel other than those involved in the writing and issuance of the procedures involved. It will include the usual internal auditing of accounts, and may require the presence of a limited number of accounting audit specialists for use on this phase.

## RELATIONSHIPS TO OTHER DEPARTMENTS

It may help give some further sense of the breakaway from traditional concepts of the Controller's office if we plot certain relationships between its sections and other departments of the company. This chart brings out clearly the degree to which every other major function in the company—manufacturing, marketing, and engineering—has one or two critical "brain centers," where forward planning and appraisal of results are performed for the head of that function. The flow of ideas and analyses between these groups and the various departments of the Controller's office is of key importance to company planning and control. In fact such an interchange, with the resulting effect on company efforts for profit, may be said to *typify* the newer concept of controllership.

For illustration of these relationships, the generation of a recommendation to top management on four basic matters is charted briefly in Figure 3. This covers:

1. Establishing a manufacturing budget.
2. Determining make or buy on a component.
3. Pricing a product line.
4. Initiating development of a new product.

Thorough study of this chart should be made for a more complete understanding of the dynamics of the Controller's organization under conditions of the organization outlined in Figure 2. The illustrations are necessarily brief and may be expanded into much greater detail by the reader.

## CONCLUSION

Let us now summarize and give the results of this discussion a wider application.

We have reviewed the general requirements for an organization necessary to implement an advanced concept of controllership, within the framework of a centralized manufacturing structure.

The prime influence in design of this organization is a simple one. It is to focus all company effort on the objective of operating efficiency, as measured by maximum profit results. To secure this, several techniques are useful and even necessary:

1. Planning (or analysis of plans) and follow-up responsibilities are joined rather than placed in separate groups.
2. Planning and follow-up duties are performed by groups separate from those which handle statistical and data-gathering services.
3. A Controls and Analysis group is the keystone of the Controller's office, being charged to analyze company programs and results in every area from the profit standpoint. This requires broad understanding of the problems of the business, and exploits accounting and control procedures intensively.
4. Cost Analysis is separated from Cost Accounting proper. This permits better servicing of manufacturing personnel and more concentrated follow-up and analysis of detailed manufacturing standards and results.
5. Cost and General Accounting are separated to insure proper recognition of the two quite different types of accounting services involved.
6. Procedures and Audit functions are broadened and focused directly on planning and control matters. The two are grouped under one head to capitalize on the special knowledge and skills of each, and to encourage a wider concept of auditing.

An attempt has also been made to indicate the dynamics of the Controller's office operation. This should demonstrate the relative sterility of an organization which does not face the *operating* problems of its company squarely. But, to do this successfully requires breadth of personnel, an organization structure which frees certain of its key people to perform careful analysis work and an intense desire to serve the company's profit objective.

The foregoing discussion has been entirely in terms of a centralized manufacturing company of medium size without the broad distribution of operating locations which might require a decentralized organization. A few comments are in order on the application of this concept to decentralized situations.

Basically, the major difference consists simply in the placing of certain key functions in a central staff group:

1. Establishing basic accounting, planning and control procedures.
2. Reviewing divisional operating results and forward programs and their compiling into over-all company presentations to top management.
3. Obtaining necessary financing, recommending dividend policy, etc.
4. Approving major capital outlays to insure conformance with previously established budgets or with current top management requirements.
5. Management development—approval or acquisition of key division personnel, insuring proper rotation and training of divisional personnel, etc.

The most immediate need for an operating division is proper coverage of the various record keeping or accounting functions plus necessary expense controls. This has often led to a simple assignment of duties between division and corporate level on this basis, such as the cases where divisions prepare the basic accounting figures and operate simple expense controls while the corporation group performs analysis work, long-range studies and policy recommendations to management. Obviously, this is not an adequate concept if the division is considered a responsible profit center. Consequently, we may even see the other extreme of strong and actually self-sufficient division controller organizations accompanied by a corporation group which merely performs elementary con-

## 1. Setting Manufacturing Budgets

| | Marketing | Manufacturing | Engineering | Controls and Analysis | Cost Analysis | Industrial Statistics | Cost Accounting |
|---|---|---|---|---|---|---|---|
| 1. Unit Production Schedule | Forecasts sales volume and field stocks by product (Merchandising and Market Research). | Develops rough requirements for direct labor and material by product (Process Engineering and Industrial Engineering).<br>Establishes plant capacity and work in process requirements (Industrial Engineering and Production Control).<br>Develops unit production schedule within plant capacity (Production Control.) | Reviews schedule to insure product availability (Administrative Engineering). | Appraises proposed price-volume relationships and competitive pricing structure (Pricing Analysis).<br>Reviews sales and field stock forecasts for progress in market penetration, proper mix and conformance with past experience and economic forecasts (Product Performance Analysis). | | Forecasts general economic and industry condition. | |
| 2. Direct Labor | | Develops detailed standards by product and operation (Administrative Engineering).<br>Projects direct labor hours needed by department and month from standards, schedule and opening inventories; makes specific allowance for set up, rework, etc. (Production Control). | Establishes final bill of material for each product (Production Liaison). | Establishes general "task" factors to be incorporated in standards, and work centers to be considered (Operations Analysis). | Reviews and accepts detailed standards in accordance with general criteria from operations analysis. Computes pertinent data on product and department costs. | | Prepares necessary tabulations and comparisons of actual costs and variances for use in analysing and establishing budgets. |
| 3. Material | | Develops detailed standards by product and operation (Process Engineering).<br>Projects material prices and lot sizes (Purchasing and Production Control). | | | | | |
| 4. Overhead and Tools | | Develops detailed department standards for indirect labor, supplies and other overhead cost components —both fixed and variable (Industrial Engineering). | | | | | |
| 5. General Review | | | | Reviews manufacturing cost performance against past experience and operating standards (Operations Analysis).<br>Appraises manufacturing cost budget against broad standards of return on investment and use of capital (Financial Analysis). | Prepares over-all statement of manufacturing cost for review and analysis. | | |

## 2. Determining Make or Buy

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 1. Locating Items for Consideration | Suggests manufacture of bought components or subassemblies having new applications with strong potential for growth (Market Research). | Establishes capacity availability and shortages (Production Control).<br>Determines bought parts similar to those already made (Process Engineering).<br>Determines bought items for which satisfactory vendors have not been located (Purchasing).<br>Determines made parts on which outside vendors can quote lower costs (Purchasing).<br>Determines made parts on which lots are of uneconomic size (Production Control). | Reviews unsatisfactory vendor parts for design or material simplification or adaptation permitting economic make (Production Liaison). | Initiates review of parts on which return on investment is below objective levels (Financial Analysis and Operations Analysis). | Reviews data on parts for which costs have been rising or falling relative to others. | Projects trends in pertinent material and capital goods costs. | Tabulates costs on made and bought parts for which costs show a rising or falling trend relative to others. |
| 2. Analyzing Make and Buy Costs | | Develops process charts, equipment needs, and labor, material and overhead requirements (Process Engineering and Industrial Engineering).<br>Obtains necessary further bids from vendors (Purchasing). | | Evaluates equipment requirements and installation costs and calculates return on investment due to saving in fabrication cost (Capital Investment Analysis).<br>Recommends major policy changes to management (Financial Analysis). | Prepares final statement of costs. | | |

## 3. Pricing a Product Line

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 1. Comparing Products with Competition | Surveys customer opinion. Obtains pertinent competitive data and establishes relative value of product characteristics (Market Research). | Examines competitive products for differences permitting cost reduction (Process Engineering).<br>Estimates detailed labor and material requirements for competitive products (Industrial Engineering). | Examines competitive products for basic design, performance, and materials advantages (Chief Product or Design Engineers). | Develops format for final comparison with competition (Pricing Analysis). | Prepares necessary comparisons of cost for competitive and proprietary items. | | Supplies necessary historical cost data to all concerned. |

| | Marketing | Manufacturing | Engineering | Controls and Analysis | Cost Analysis | Industrial Statistics | Cost Accounting |
|---|---|---|---|---|---|---|---|
| 2. Determining Price-Volume Relationships | Estimates effects of price changes in various territories and by major customer classifications (Field Sales).<br>Estimates effect of specific promotional expenditure changes on volume (Merchandising).<br>Develops correlation studies relating price, promotion expense and unit volume experience (Market Research).<br>Projects competitive reaction to price changes (Field Sales and Market Research). | | | Reviews Marketing's data and calculations in detail (Pricing Analysis). | Prepares detailed statements of variable and total costs and profits at various price levels in the format determined by Price Analysis. | Reviews Marketing's conclusions against broader industry experience and trends. | |
| 3. Establishing Final Prices | Recommends relationships to hold between company products (Merchandising). | | | Develops proposed pricing structure based on maximizing profit on variable and total costs (Pricing Analysis and Financial Analysis), considering investment required. | | | |

4. Initiating New Products

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 1. Establishing the market. | Studies needs of potential end users to develop industry and company share (Field Sales and Market Research).<br>Develops price-volume relationships (Field Sales and Market Research). | | Determines general technical feasibility of product proposals.<br>Evaluates performance and specification advantages of proposal versus competition (Chief Product or Design Engineers). | Recommends review of product areas showing declining penetration or profits (Product Performance Analysis and Financial Analysis).<br>Reviews market forecast and price-volume curve; establishes targeted unit cost (Product Performance Analysis and Pricing Analysis). | | Determines basic economic trends pertinent to a proposed product.<br>Recommends broad product areas for detailed examination by marketing. | |
| 2. Estimating Development Costs and Capital Requirements | | Evaluates preliminary design and estimates labor and material requirements (Process Engineering and Industrial Engineering).<br>Determines general plant and equipment needed for production and experimental fabrication (Process Engineering). | Prepares preliminary design (Chief Product or Design Engineers).<br>Develops detailed plan for development covering: detailed dates for completion of key items; manpower by type; fabrication costs; and testing required (Administrative Engineering). | Reviews development plan for thoroughness and adequacy (Product Performance Analysis).<br>Reviews all plant and equipment (including test facilities) requirements. (Capital Investment Analysis).<br>Develops needs for working capital to support sales volume (Financial Analysis). | Evaluates projected experimental fabrication costs. | | Supplies necessary historical cost data. |
| 3. Evaluation | | | | Analyzes total investment required and rate of return to be obtained against company objectives for growth and return. Prepares final report for management (Financial Analysis). | Prepares necessary statements of forward sales, costs and investment. | | |

Fig. 3

solidation accounting plus the financial responsibilities mentioned.

To a large extent the distribution of functions obviously depends on the exact philosophy of decentralization held by the corporation's top management and the relative strength of personnel involved.

These brief remarks should help determine the structure of a financial organization for a decentralized corporation, reflecting the principles in this paper.

## REFERENCE

(1) Cochran, E. B., "What is a Controller," *The Journal of Accountancy*, July 1955.

**CONFERENCE AND CONVENTION**

***The Eleventh Annual Conference and Convention of AIIE will be held:***

**DALLAS, TEXAS**

***Sheraton-Dallas Hotel***

**MAY 12, 13 AND 14, 1960**

**PLAN NOW TO ATTEND**

# Least-Cost Testing Sequence

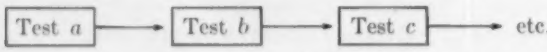
*by* **H. WALTER PRICE**

*Diamond Ordnance Fuze Laboratories*

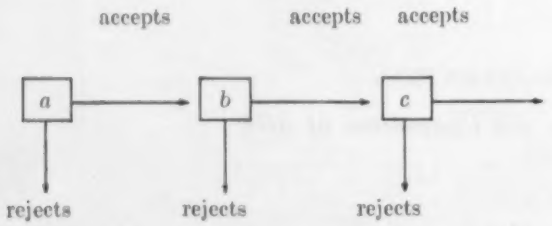
COMPLEX mechanisms are usually subjected to a series of different non-destructive tests. Often, the order of testing is not significant from the technical standpoint. Thus, whether the length or weight of a mechanical part is measured first is usually not important since neither measurement affects the part in any way.

However, from the economic standpoint the order of testing *is* usually significant. Thus, there will, in general, be one sequence of testing which will result in the least total cost of testing. In some cases, of course, there may be many such sequences of equally low cost; or there may be many sequences with insignificant cost differences. In many cases, however, the cost difference between the least-cost sequence and other sequences is sufficiently large to warrant some effort to select the least-cost sequence. This is particularly true when repetitive testing is planned, (i.e., acceptance testing in a continuing production).

Consider, then, a series of $n$ non-destructive tests on an item wherein the order of testing is not technically significant. Label each of these tests $a, b, c, \ldots$, etc. Then, the number of possible sequence of these tests, $a, b, c, \ldots$ is $\lfloor n$ . One possible sequence is alphabetical.




Now, each test will have rejects. Thus, the rejects from test "$a$" will not be subjected to tests $b, c, \ldots$; the rejects from test "$b$" will not be subjected to tests $c, d, \ldots$; etc.




Each test $a, b, c, \ldots$ will have an entailed average cost per item of testing, $C_a, C_b, C_c, \ldots$, etc. (This cost includes all costs such as labor, maintenance, depreciation, amortization, etc. as may be pertinent.) It may be convenient to measure this cost in man-hours.

Likewise, each test $a, b, c, \ldots$, will have an average reject rate, $R_a, R_b, R_c, \ldots$, etc.

One method of determining the least-cost sequence might result from the following reasoning: Since the highest number of items go through the earlier tests and the least numbers of items go through the later tests, put the test having the lowest per-item cost first, the test having the highest per-item cost last, and order the others between these by the same rule.

Another method of determining the least-cost sequence might result from this reasoning: Put the test with the highest reject rate first, the test with the lowest reject rate last, and order the others between these by the same rule. This sequence will result in the least number of individual tests.

If the set of tests $a, b, c, \ldots$ are such that the test having the highest reject rate has the lowest per-item cost and the other tests have a similar inverse relationship of reject rate and cost, both of the foregoing methods will result in the determination of the same least-cost sequence. Hence, either method would be valid.

In the converse case, the test having the higher reject rate would have the highest per-item cost and the other tests would have a similar direct relationship of reject rate and cost. Then, the two above methods are directly contradictory and neither is valid.

In actual situations such simple relationships of rejects rate and cost would be fortuitous especially for larger values of $n$. In general, there will be a random relationship between reject rate and per-item cost of test.

## THE LEAST-COST SEQUENCE METHOD

What is needed, then, is a method considering both factors, reject rate and per-item cost of test. Consider the total cost, $C_T$, of operating a test program. This total cost is obviously the cost of operating the first test position, plus the cost of operating the second test position, plus the cost of operating the third test position, etc.

The cost of operating each test position is the per-item cost of test times the number of items tested. For the first test position this is:

$$\text{Cost}_1 = NC_1,$$

where

$N$ = number of items entering test,

$C_1$ = per-item cost of test number one

The cost of operating the second test position is:

$$\text{Cost}_2 = N(1 - R_1)C_2,$$

where

$R_1$ = reject rate of test position 1.

$C_2$ = per-item cost of test number two.

The factor $(1 - R_1)$ is included in this equation since the number of items entering test position 2 is the number, $N$, entering test position 1 reduced by the amount of rejects from test position 1, (i.e., if 100 items enter test position 1, and $R_1 = 0.02$, then 98 items will enter test position 2, since two of the items were rejected in position 1). In general, then,

$\text{Cost}_n = N(1 - R_1)(1 - R_2)(1 - R_3) \cdots (1 - R_{n-1})C_n$ is the cost of operating the $n$th test position.

If an accept rate be defined as:

$$A_n = 1 - R_n,$$

then the expression can be written as

$$\text{Cost}_n = N(A_1 \cdot A_2 \cdot A_3 \cdots A_{n-1})C_n.$$

The total cost of operating the whole test program is then:

$$\begin{aligned}\text{Cost}_T &= \text{Cost}_1 + \text{Cost}_2 + \text{Cost}_3 \cdots \text{Cost}_n \\ &= NC_1 + NA_1C_2 + NA_1A_2C_3 + NA_1A_2A_3C_4 \\ &\quad + \cdots + N(A_1A_2A_3 \cdots A_{n-1})C_n \\ &= N[C_1 + A_1C_2 + A_1A_2C_3 + A_1A_2A_3C_4 \\ &\quad + \cdots + (A_1A_2A_3 \cdots A_{n-1})C_n],\end{aligned}$$

where

$\text{Cost}_T$ = total cost of operating entire test program,

$N$ = number of items entering test program,

$C_n$ = per-item cost of $n$th test,

$A_n = (1 - R_n)$ = accept rate of $n$th test.

$R_n$ = reject rate of $n$th test

Define $C_T$ as the per-item cost of the whole program. Then,

$$C_T = \frac{\text{Cost}_T}{N}.$$

And,

$$C_T = C_1 + A_1C_2 + A_1A_2C_3 + A_1A_2A_3C_4 + \cdots + (A_1A_2A_3 \cdots A_{n-1})C_n \quad \text{Eq. 1.}$$

The least-cost sequence, then is that sequence of tests $a, b, c, d, \ldots$, which will minimize $C_T$.* Therefore, the procedure is to calculate $C_T$ with test "$a$" in position number 1, test "$b$" in position number 2, test "$c$" in position number 3, etc. This process is to be continued with all combinations of tests and positions. Finally, the procedure is to select that combination yielding the lowest value of $C_T$. This sequence, by definition, is the least-cost sequence.

For a small, $n$, of tests (say 2 or 3) this procedure is feasible for manual computation since only two or six calculations are necessary. For larger sizes of $n$, a computer is advisable, since the total number of possible sequences is $\lfloor n$ .

* Implicit in this treatment is the assumption that the values of the individual $A$'s and $C$'s for each test are independent of the position of the test in the sequence.

## ILLUSTRATIVE EXAMPLE

This analysis was applied to an actual testing program consisting of five tests. These tests are listed in Table 1 in the original sequence in which they were being conducted prior to the analysis. The test cost figures are in terms of man-hours.

TABLE 1

| Test | Accept Rate | Test Cost per Item in Man-Hours |
|---|---|---|
| Visual | .998 | .08 |
| Shock | .95 | .584 |
| Electrical | .95 | .232 |
| Distortion | .965 | .124 |
| Vibration | .35 | .64 |

This particular sequence was established by the test foreman in a somewhat arbitrary basis. The visual test was put first since it was "easy to do." (Note the low test cost per item.) The vibration test was put last because it was "hard to do." (Note the high test cost per item.) On the choice of the first and last tests, the foreman seemed to be intuitively following the rule "put the least-cost test first, and the highest-cost test last." Note, however, that the other three tests are in the sequence of inverse cost order and were apparently arbitrarily placed.

The actual total test cost per item ($C_T$) of this particular sequence was calculated by Eq. 1 to be 1.55 man-hours per item.

Table 2 shows the same tests rearranged in the least-cost sequence.

TABLE 2

| Test | Accept Rate | Test Cost per Item in Man-Hours |
|---|---|---|
| Vibration | .35 | .64 |
| Distortion | .965 | .124 |
| Electrical | .95 | .232 |
| Shock | .95 | .584 |
| Visual | .998 | .08 |

It will be noticed that the least-cost sequence is the exact opposite of the original sequence intuitively established by the foreman. Thus, the foreman's first test should have been run last, and his last test should have been run first.

The actual total test cost per item ($C_T$) of the least-cost sequence was calculated by Eq. 1 to be 0.978 as compared to a total test cost per item of 1.55 for the original sequence. This means that the using of the least-cost sequence in lieu of the original sequence resulted in a cost saving of 37 percent.

# The Production of Values Added by Marketing*

*by* **AL N. SEARES**

*President, National Sales Executives-International, Vice President, retired, Remington Rand Division, Sperry Rand Corporation*

THROUGH the applied principles of scientific management we have developed the productive capacity of the United States to almost half of that of the entire world. This productive ability of our farms and manufacturing facilities has prompted some economists to refer to this condition as a "mass production complex." To me, this is indicative of an apparent failure to realize that "mass consumption" is the balance wheel that provides the alternate heart beat—to assure an ever increasing *in phased* Gross National Product.

In short, our high-capital, high-output economy, which has achieved the highest standard of living ever dreamed of in the world's history, can be said to rest upon the efficiency of our distribution system in transporting and merchandising the end products of our growing production facilities. And as our industrial productivity is stepped up through automation and other technological advances, those engaged in distribution must equate this challenge with the development of effective marketing techniques.

## MARKETING AN INTEGRAL PART OF THE TOTAL PRODUCTION PROCESS

The physical processing of a product is only one aspect of manufacture. Marketing does not follow production—it is part of it. Actually, to an ever increasing extent, market research precedes product development and the fabricating stages of production. From an economic point of view, production of a product or service is not complete until it is in the possession of the ultimate consumer.

Because of the historical emphasis on farming and manufacturing as the basic production activities, many persons still mistakenly think of marketing as an added cost that has little justification in economic or social utility. If we think, as modern economists do, of production as the creation of economic utility, marketing provides the time, place and possession utilities which are just as essential as the forming of the product in satisfying the needs of the consumer.

Products that sit unsold in a factory warehouse—or excessive products of the farm—are obviously in an incomplete state of production from the point of view of the user, even though physically they represent the output of one of the stages of production. *For production to be completed, it must be made available to the user at a place, at a time, and in a manner that is most convenient and desirable for him.*

Over the last 100 years, there has been a drastic change in the role of marketing in the economy. Formerly there was a relatively close link between the producer and the consumers of many types of goods. Farmers typically brought their goods to market in the nearest town or to a nearby miller for processing for a local market. The continuing industrial revolution and the development of modern forms of transportation have greatly altered these limited patterns of distribution. Modern technology and mass production involves concentration of production in large units. This has forced a physical separation between manufacturers and the bulk of the ultimate users. Instead of serving local markets, manufacturers have to serve regional and national markets, and frequently, international markets, in order to maintain profitable manufacturing ratios.

Achievement of our high standards of living has made it possible for consumers to buy more than the basic necessities. This means that they have a choice of what to buy, or whether to buy at all.

Therefore, they must be persuaded to buy by means of advertising, selling, attractive packaging, convenient ways of purchasing, credit, and all the other techniques which are characteristic of modern marketing. At the same time, the much wider range of products available has greatly increased the complexity of the marketing operations. We have only to consider the variety of items that a department store or a super market finds it necessary to stock to visualize the impact of these developments in marketing.

## USING THE VALUE ADDED BY MARKETING TO MEASURE PRODUCTIVITY

If we accept marketing as a basic part of the productive process, it is important to be able to measure its con-

* Based upon a presentation to the New York City Chapter of AIIE.

tribution to economic activities. Having a way of measuring the output of various marketing activities helps to emphasize the positive aspects of marketing. Such data will highlight the fact that marketing makes a substantial contribution to our over-all production capabilities. Data on the "performance services" by marketing also makes it possible to evaluate the productivity and effectiveness of marketing operations and to make comparative analysis of marketing costs among different patterns of distribution.

## THE PROBLEMS OF MEASUREMENT

Figures on the total sales of a merchandising organization, such as a department store, do not provide a valid measure of its output. A large proportion of the total value of the goods it sells represents activity at earlier stages of production. The same problem applies to measuring the value of output of manufacturing plants. For example, one firm may purchase parts and merely assemble them into a final product, while another firm may fabricate the components it uses. Although the second firm has actually carried out more productive activity, the total sales volume of the first firm is likely to be as much or more.

## THE VALUE ADDED CONCEPT IN MARKETING

To get around this problem of duplication in measuring output in manufacturing industries, the Census of Manufacturers has for many years collected and published data showing the value added by manufacturing for each industry. This figure is obtained by subtracting from the total sales reported, the cost of the goods or materials bought by each firm and the cost of supplies and services such as fuel, power, and packaging materials.

Many marketing experts have been proposing that a similar approach be used to measure the output of marketing activities. This is how this concept is applied. The cost of the goods purchased for resale by each marketing firm, plus the cost of supplies, facilities and services used, would be subtracted from its total sales.

This approach to measuring the value of the marketing services performed by a firm, or industry, rests upon the premise that the economic value of a product is determined by what people will pay for it. Therefore, the difference between the acquisition costs of merchandise for resale, plus certain basic marketing expenses, and the price paid by the ultimate consumer, represents the "value added" for marketing services. As in the case of manufacturing, this difference consists mainly of wages paid to employees, interest on capital investment, rents on property or equipment and the profits accruing to the owners of the business. This concept is consistent with the procedures used to measure the Gross National Product, which is compiled by allocating to each factor of production the total value of its services.

## APPLYING THE VALUE ADDED CONCEPT

With the value added concept, we now have a way of looking at marketing from the viewpoint of what it is accomplishing rather than only what it is costing. For this reason its use has been proposed by a number of leading marketing authorities. Professor T. M. Beckman of Ohio State University has played a leading role in suggesting and promoting the adoption of the value added by marketing concept.

Unfortunately, however, much of the statistical data necessary to actually prepare such figures is lacking. The Chamber of Commerce of the United States through its Domestic Distribution and its Business Statistics Committees, the National Sales Executives, the National Association of Manufacturers, and others are actively campaigning for the provision of the necessary basic statistics. This could be accomplished in large part by the addition of several questions to the regular "Census of Business" form. In addition, the trade associations in the marketing field are being encouraged to utilize the value added concept in their statistical and cost information programs.

## MARKETING FUNCTIONS AND WHAT THEY CONTRIBUTE TO PRODUCTION

On the basis of the evidence presented, I think that we can agree that marketing makes an essential contribution to our economic and physical well being. Further, it is evident that marketing expenditures represent a value which has been added to the output of farms and factories and not an extra, unnecessary cost. Marketing, of course, is not merely a single function but is a complex set of specialized activities, each contributing to the effectiveness of the over-all marketing operation. The importance of these special functions varies considerably, depending upon the product and the way it is marketed, but each has a unique and essential role. By understanding the nature and scope of each marketing activity, we can get a clearer picture of the total marketing function. Let's consider ten of these major functions in the marketing process.

### TRANSPORTATION

The movement of goods to market has long been a vital part of distribution. The traders and merchants seeking to find new markets and to bring back the products of far off countries played a major role in the explorations and discoveries that opened up the modern world. The evolution of a factory system and the resulting growth of mass marketing has been based on the development of modern transportation facilities. Marketing on a regional or national basis, rather than local, implies a rapid and economic means of getting goods from factories to consumers. Without railroads, and steamships it is unlikely that industrialization could have proceeded very far. This has been accelerated by door-to-door truck trans-

portation—and now speeded by air freight—further extending the ability of producers to reach out for profitable new markets.

### INVENTORY PLACEMENT TO FACILITATE SALES

One of the ways that marketing adds to the economic utility is making goods available to customers at a time and place that is convenient for them. In order to do this, stocks of goods must be maintained at every level of marketing. To make it possible for a customer to walk into a store and pick out the article he wants from a shelf means sizable expenditures by manufacturers, wholesalers, and retailers, in space and equipment, for warehouse and stock room personnel, and for inventory carrying charges. It also requires substantial commitments of working capital. With the enormous volume and diversity of goods made available by modern technology, the costs of storing goods have risen sharply. Control of these costs through more and better information on customer needs, inventory control and through introduction of improved handling techniques, is one of the most critical problems currently faced by marketing firms.

### POINT OF SALE SERVICES IN MARKETING

Most of us are responsive to personal contacts. Personal selling is a marketing activity of which we as purchasers are very conscious. The importance of salesmanship grew naturally out of the fact that people frequently have to be persuaded to buy a particular type of article or a particular brand. When industrialization increased the number and variety of competing products, and made it possible for people to have a wider choice of what they could buy, it was natural that point of contact selling was needed to motivate buyer acceptance. Along with this, however, has come an increased emphasis on the service aspects of selling.

Such a service can range from the information that retail clerks can provide on prices and styles, and simple explanations of the features of various products to the technical sales engineering required to plan, consummate, install and even maintain many products of our factories.

It is generally accepted that sales contacts are one of the main channels through which specific product information can be given to users and this is responsible for the growth of service type selling. At the same time we can observe a lessening of the importance of the application of personal salesmanship to many types of marketing. For example, in certain kinds of retailing, product information is not as critical or it can be passed on effectively in other ways. The result is that professional salesmanship, as distinct from merely passing goods across the counter, will be increasingly a combined servicing, information and sales function. It will tend to persist mainly where personalized service is required. This naturally means a drastic upgrading in the qualifications required for many types of salesmen. A shortage of well trained, qualified salesmen is one of the major problems in marketing today. And there is a substantial lead time involved in recruiting top notch sales personnel and the knowledgeable tooling up process for the sales job that must be done.

### DEMAND CREATION WITH PERSUASIVE COMMUNICATIONS

Demand creation is one of the newest and most striking of the activities that support our modern mass marketing operations. Broad distribution of many types of goods, particularly new products, cannot depend on merely reaching an existing, ready made market. The impetus to purchase must be stimulated by arousing the interest of potential users. Demand creation is a concept relatively new even among marketing men and one that is just beginning to be recognized by some economists. To get some background and insight as to the role of demand creation, it is necessary to go back and look at the way in which marketing operations were conducted even as recently as fifty years ago.

To a large extent, purchases, even by those relatively well-to-do, were confined to what may be considered basic necessities. What little advertising was done, consisted mainly of notices that such and such type of goods was available from the advertiser. It was generally considered that the need for the product was established and advertising and other promotional work would be aimed at attracting the customers that were already in the market.

With the rise in living standards achieved by modern technology, entirely different approaches to marketing have emerged. Today, the majority of consumers have incomes which enable them to make purchases beyond what might be considered basic necessities. After their basic needs are satisfied, they thus have a freedom of choice, not only of which product or goods they want to buy, but whether they will purchase at all. At the same time, the Nation's factories are tooled up to produce vast quantities of not absolutely essential products. Our continued prosperity depends to a large extent upon the utilization of this productive capacity. To accomplish this, the income receiving and spending units of the Nation must be induced to consume beyond the minimum subsistence levels. This has brought about the development of advertising in its various forms as a major marketing force. Modern advertising, primarily, is directed toward motivating the consumer to buy articles he is not already aware he needs or wants rather than only persuading him to buy from a particular firm.

This year, advertisers will spend more than 10 billion dollars to stimulate demand for their products and to persuade buyers to give or continue their patronage. These vast expenditures on various forms of advertising have made it a major support of our vehicles of mass communication: newspapers, magazines, radio and tele-

vision. However, advertising is not restricted to this media. Direct mail is an important factor in the marketing of many types of goods. Catalogs, with their well illustrated, tempting array of products, serve as a demand creation force.

Similarly, under the heading of merchandising and sales promotion, many techniques are used at the point of sale to attract customers or remind customers of the satisfaction they can get through purchasing a particular product. The displays and other visual materials used at the point of sale are a potent force in arousing impulse purchases. I know that you have all had my experience of leaving a store loaded with unplanned purchases, when the shopping list consisted of only a tube of toothpaste or a loaf of bread.

### PACKAGING WITH CONVENIENT MAKE-READY FOR THE USER

In a physical sense, packaging might be considered part of the basic production process since goods are frequently packaged before they leave the factory. Marketing activities involving the package are, however, often a major factor determining the sales success of a particular product. Through the effective use of color and design, attractive packages are created. The appearance of the package and its attention attracting power play a major role at the point of sale in influencing the buyer's choice of brand or in causing impulse purchases. In full recognition of this, consumer goods manufacturers place great stress on developing the so-called "brand image," which they hope that customers will recognize and respond to. The package is frequently featured in the firm's advertising, and considerable effort is devoted toward getting stores to give the best possible shelf location and to permit the use of elaborate merchandise displays.

By providing articles to the final consumer in a convenient form, packaging contributes substantially to the total utility it provides. Modern packaging keeps the merchandise fresh and clean, makes it possible to offer a range of sizes and quantities; and makes it easy for the customer to see what he is buying. In addition, many packaged products such as frozen foods, pre-mixed, or prepared foods provide convenient "make-ready" for the user.

### CREDIT OR THE TRANSFER OF WORKING CAPITAL TO A "SOLD INVENTORY"

Although the granting of credit to purchasers may appear to be largely a financial transaction, in actuality, it is a major aspect of many marketing operations. Without the extensive facilities for installment and credit purchases, the mass marketing of such products as automobiles and household appliances would be severely restricted. Thus the providing of credit is a major marketing tool in such fields. It is a major element in creating time utility for the ultimate purchaser, since he is able to obtain the product when he needs and wants it, rather than waiting until he has accumulated the necessary funds.

### CUSTOMER SERVICE ACTIVITIES

Another important marketing function that is sometimes over-looked is the extensive service facilities provided by many manufacturers to maintain and repair their products. Customer satisfaction, both for consumer and idustrial type goods depends on trouble free performance in use. The manufacturers of many kinds of products find it necessary and desirable to assure customer satisfaction by setting up their own service facilities or by encouraging and guiding independent service firms. Products are often backed up by guarantees under which the manufacturer provides any necessary service for a certain period of time. Even when service is paid for by the customer, which is true in most cases after the guarantee period is over, the quality of the service available can be an important marketing factor.

### MARKET RESEARCH

The shift from small scale to mass marketing conditions has greatly increased the complexity of marketing operations. As a result, a great need has developed for statistical and economic information on sales and marketing developments. To provide such needed information, the Market Research Department of today is a vital communication aid to all levels of management.

It is now performing a major role in the conduct of marketing activities. Marketing information aids many companies in effectively planning and organizing their sales activities. Sales forecasts guide sales campaigns for existing products and help in the selection of new products to market.

Efficient utilization of costly mass production facilities is also largely dependent on being able to plan production well in advance of operations. Sales forecasts make it possible to effectively schedule production and even out possible ups and downs in output which can cause production problems. The balancing of sales and production through the use of sales forecasts can be particularly useful where a number of products are being made, each with its own marketing pattern.

By providing marketing management with a wide range of data on markets and internal sales operations, market research contributes greatly to the fact-power resources available to management to plan and control marketing operations.

The application of operations research techniques also helps management in the decision making process, as regards long range planning.

### PRODUCT PLANNING

With the recognition of the importance of coordinated production planning and marketing has come the devel-

opment of product planning as a specialized function. Frequently, product planning has been done in a haphazard fashion. New product decisions have been based on developments or ideas originating in a firm's laboratories, with little evaluation of their potential commercial success, or on an unsubstantiated feeling that a certain quantity of a proposed new product could be sold. Product planning is now becoming organized on a more formal basis, taking into account all the various marketing factors as well as production and financial factors which should enter into a decision to undertake the production and marketing of a new product. This new marketing function is extremely important for several reasons. The growth of the economy depends to a large extent upon the continuing development and commercial success of new products. Likewise, the growth of individual firms is greatly influenced by their ability to develop and market a succession of new products.

With the tremendous amounts now being devoted to carrying out commercial research and development activities, it is very important to be able to determine which new products or fields offer the greatest promise. Research and development work on military and commercial projects, is now costing the Nation well over 5 billion dollars a year. A significant proportion of these expenditures is for projects whose objective is the development of new commercial products. Many of these projects are doomed to failure because of inadequate planning and failure to properly evaluate the potential market. The return on investment that can be expected from the introduction of a new product should be the major criterion in determining which new products to develop, but frequently, this factor is not considered until the product is well on the way to being manufactured and marketed. The importance of new product planning is accentuated when there is a long lead-time between the conception of the idea and putting it into production. This situation is quite typical of the electronics and machinery industries, among others, where there is a heavy investment in research and development even before the costs of tooling up are incurred.

### PROFITS—THE VALUE ADDED TO GROW WITH THE ECONOMY

The last production value in the marketing process is, of course, a profitable return on the invested capital as made possible by the applied use of successful management practices and the utilization of the needed resources. From these profits come additional capital for business growth and the tax revenues to maintain our "freedom of choice" economy.

It is this "freedom of choice" in the market place that produces the 100 billion plus sales transactions, that currently account for our total annual Gross National Product. Here then, marketing performs its major and final function in furthering the sustained economic growth and prosperity of the United States.

## NEW CONCEPTS IN INTEGRATED MARKETING MANAGEMENT

In taking up the various marketing functions one at a time, I certainly do not want to leave the impression that these functions represent separate activities, without a joint purpose. To some extent, the contrary is true —for example, in many firms, advertising and public relations programs are not meshed in with the sales operations they are presumably intended to support. One of the most significant current developments is the growing recognition that, to be effective, marketing activities must be integrated. As a result, more and more companies are setting up what they call a Vice President in charge of all the Marketing Operations.

He is also responsible for coordinating marketing programs with production and financial operations at the top policy level. Under this form of organization, the Marketing Manager makes sure that the needs and interests of the customer are given top priority at every stage of the firm's operations. This means that he has a direct responsibility in determining what products should be made, how they will be designed and packaged—providing adequate service facilities, and in the planning of the supporting advertising and sales promotion programs, while at the same time, overseeing the operations of a productive sales organization.

The increased acceptance of this concept by leading firms is a further sign of the importance of the role of marketing in today's complex economy. The chief marketing executive is charged not only with directing the sales effort but with making sure that the sales operations reflect fully the financial situation of the company. Thus he participates in the top level financial decisions and has an important voice in developing the over-all budgets for the firm. With this new approach to marketing, these marketing executives must increasingly utilize such advanced management techniques as motivation research, market measurement and have access to accurate, up-to-date statistical intelligence on sales variations from previously established expectancies.

## INCREASING THE EFFICIENCY OF MARKETING OPERATIONS

Marketing, in making its contribution to the Gross National Product, also provides buyer benefits to the customer. In this process, marketing is under the same obligation and pressure as manufacturing in finding ways to improve the efficiency of its operations, and it must be with the substantial increases being made in our rapidly expanding industrial facilities.

This puts marketing under continued pressure to keep pace with the growth of factory productivity, lest marketing costs impede the translation of this increased production into effective purchasing power. The marketing management of every firm must also face up to the stiff competition which has become increasingly evident in

the past several years and which is being intensified.

The adoption of "consolidated marketing management" is certainly one approach to improving the effectiveness of distribution. Another important method of attaining greater efficiency is the administrative control of marketing operations. A major instrument of control is the provision of better marketing intelligence by developing more data on all phases of marketing. In this respect, the process of obtaining and utilizing current "marketing intelligence" can be compared to the importance of electronic gear to control the flight of a modern missile.

Like the importance of radar to the military, business management also needs a nerve center to report and analyze current marketing developments for surveillance as regards corrective counteraction. The Market Research Department, working closely with operations research and long range planning personnel can collect, and evaluate such pertinent data for more informed and effective management.

Here are some of the critical points where marketing management can develop "guidance facts" to improve sales production:

1. To determine as much as possible, what potential customers need and want—and well in advance of production so that these needs can be reflected in product design.
2. To periodically determine the most effective channels of distribution for particular products and related marketing possibilities.
3. To constantly review methods to optimize the turnover of "unsold inventories" in the distribution pipe lines. This means having unit inventory balances in the right amount to equate user demand, thereby avoiding excess inventories, which pile up burdensome expenses in carrying costs, or the counterpart in frequent restocking expense.

Many new techniques in the field of management sciences have been developed to meet this need. Among the most noteworthy is the rapidly accepted use of high speed, data automation systems through the use of electronic computers. This high speed, data processing system makes it possible to process the input data, in sales orders, from almost immediate acknowledgment, with a scheduled shipping date, through shipment and invoicing, in a chain of progressive operations.

This enormous capacity to digest and process information (mostly without human intervention) permits up-to-date sales statistics as a by-product of normal accounting operations. In the process, inventory changes can be recorded with automatic determination as to reorder requirements.

The *sales-power of consolidated marketing management* has the resources at its command to produce the "values added" both to motivate and accelerate increases in our Gross National Product. To do this, it must be more knowledgeable and responsive to the "sales production" job that must be forthcoming lest an "economic sputnik" be our undoing.


*The newest developments in the field of human engineering*

**Research Techniques in Human Engineering**

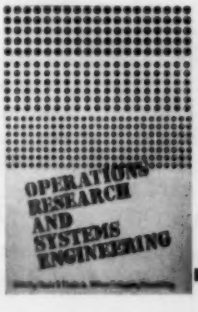
by Alphonse Chapanis

Here for the first time are compiled the operational methods and problems from the fields of industrial engineering, psychology, anthropometry, physiology, and statistics—in a practical handbook for the human engineer. *Research Techniques in Human Engineering* provides essential background information for the student of human engineering and should be of great interest to those actively engaged in industrial engineering, operations research, systems engineering, experimental psychology, and scientific management.

*336 pages, tables, 49 illustrations, index*
$6.00

**THE JOHNS HOPKINS PRESS**

*Baltimore 18, Md.*




*To be published in December*

**Operations Research and Systems Engineering**

edited by Charles D. Flagle, Jr., William Huggins and Robert H. Roy

The best book yet in the field of operations research. For all those connected with the newest and most rapidly expanding management service, this book will be of enormous and long-continued usefulness. Basic concepts and methods of operations research and systems engineering are discussed, and the specific techniques that play major roles in these related disciplines are thoroughly investigated.

*550 pages*
*charts*
*figures*
$10.00

# The Application of Sample Survey Methodology to Work Sampling

*by* **ALBERT MINDLIN***

*Technical Assistant to the Chief, Statistics Branch, Bureau of Old-Age and Survivors Insurance, Social Security Administration, U. S. Department of Health, Education, and Welfare*

ONE of the problems continually facing management is obtaining valid and reliable information on time spent by personnel on various kinds of activities and average unit times for measurable items. Such information is essential for budgeting, planning, staffing, setting work standards, and for a variety of other management activities. Classical time studies have sought to deal with this problem. In recent years work sampling has become popular as a more statistically valid and reliable alternative to the classical time study approach in many areas of work.

Work sampling was first used in industry to estimate "down time" of machines, and was called "ratio delay." In more recent years it has been used effectively to measure work throughout an organization. However, most of the literature on ratio delay and work sampling has dealt with comparatively few activities and only simple random sampling (1). This paper presents the statistical methodology of work sampling applied on a larger scale than has generally been presented in the literature, and to a much larger and more complex set of activities. Large-scale application of work sampling in the Bureau of Old-Age and Survivors Insurance involves stratification, clustering, and multi-stage sampling, and more elaborate methods of estimation than have generally been used in the past. In effect it utilizes some of the more sophisticated techniques of sample survey design. The result is valid and reliable statistical information on a large scale, obtained in an efficient way with respect to the size of the organization and the complexity of the subject matter, and is usable with great flexibility.

## THE ORGANIZATION SAMPLED

The Bureau of Old-Age and Survivors Insurance, Social Security Administration, U. S. Department of Health, Education, and Welfare, operates nearly 600 district offices throughout the U. S. and its territories, ranging in size from 5 to 80 employees each. The activities of a district office are highly varied between offices, between individuals, and even for a single person. They range from simple office routine activities to complex and lengthy interviews with claimants for social security benefits which deal with the claimants' entire work history, household composition, and numerous other characteristics pursuant to the Social Security Act. The work also includes public relations and contacts with public and private organizations on matters pertaining to the federal social security system. A substantial portion of the work is carried on outside the office.

It is clearly a task of considerable difficulty to prepare a reasonably accurate budget, set proper standards, and obtain other vital management information for a field staff of this type. The many activities must be classified in a relevant way, the average unit times of activities resulting in production items determined, and estimates made of expected "workload." The problem has been complicated in recent years by vast changes in federal statutes that have been made since 1950.

## PAST AND PRESENT

In the past, periodic surveys were made of a sample of district offices. For several weeks each employee in the district office was required to maintain a complete daily record of the length of time he spent on each of a large variety of activities. This procedure had several disadvantages. It was time-consuming for a large number of employees and tended to interfere with their regular activities. Consequently, it was restricted to a few weeks each year or two. This made it difficult to assess rapidly the effect of new legislation on district office patterns and productivity, or to determine seasonal variations. Also the validity of the data was difficult to evaluate.

The method of work sampling, in addition to yielding statistically valid and reliable data, has greatly simplified the procedure within the district office, vastly reduced the time required, almost eliminated the active involvement of the bulk of employees, and permitted continuous investigation.

## THE STATISTICAL DESIGN

Average time spent per unit of production is required at the present time for 18 measurable activities. Propor-

* Currently Chief Research Statistician, Department of General Administration, Government of the District of Columbia.

tional time spent is sought on these activities and on 6 non-measurable activities. This information is needed for a variety of classifications. The classifications are the basis for the stratification of the universe. The data are classified by 4 time divisions (in-office during the regular work day, out-of-office during the regular work day, in-office overtime, out-of-office overtime); 6 position-types (management, field representatives, claims representatives, claims clerical, receptionist, and other clerical); nationally, and by 11 geographical regions. In addition to time-division, position-type, and regional classification, which are desired for administrative uses of the data, the district offices are sub-stratified within each region by a measure of size, which greatly increases the statistical efficiency of the sample. An ultimate stratum consists of one time-division, one position-type, one region, and one size-group sub-stratum.

Each ultimate stratum contains several district offices. Each district office may be regarded as a cluster. The cluster consists of the infinitude of instants of time in a particular ultimate stratum and in a particular district office—e.g., the time spent by field representatives out-of-the-office during the regular work day in district office 000 which is located in size-group A of Region IV.

The design is a 2-stage sample. Within an ultimate stratum one or more district offices are randomly selected with equal probability. Within the selected district office a random sample of instants of time is selected each day at which the activities of the individuals are tallied. Thus, the ultimate sampling unit is an instant of time. This is one of the fundamental distinctions between work sampling and classical time studies. No information is obtained over any interval of time in this project.

## THE ACTUAL PROCEDURE

In order to develop a workable and efficient design and procedure, two pre-tests were conducted, first a small dry-run to test procedures within the district office, and then a full-scale national pilot study which tested instructions, forms, procedures, processing, estimating formulas, training, and staff acceptance, and which obtained information on costs and variability necessary to develop an optimum design. The full continuing project consists of a national sample of $\frac{1}{6}$ of all district offices at any time. Each two months these are replaced by another randomly chosen set.

The actual procedure employs three basic forms—a random sample time sheet, a mark sense tally card, and a control record with a removable name-list overlay. The random sample moments are selected in the central office. Persons working in the office during the regular work day are tallied 6 times a day. Several hundred sets of 6 random moments have been constructed in the central office, subjected to tests of randomness, placed in time order, and raked to guarantee an interval of at least 15 minutes between successive sample periods. Each random sample time sheet is placed in a sealed envelope and a two-month supply sent to the district office. One is used each day.

Within the district office the entire procedure is controlled by one person called the recorder. Work in the office during the regular work day is tallied by the recorder, using a separate mark sense card for each position-type. The recorder places a name roster over a control sheet each day. No names appear on either the control record or the tally cards. Work in the other time-divisions (out-of-office regular time, and in and out-of-office overtime) is self-reported. A person "checks out" with the recorder when he leaves the office and "checks in" when he returns. The recorder enters the time in the control record alongside the employee's name, and notes whether the absence is on leave or business.

In the morning the recorder opens a sealed envelope containing the random sample moments. When a sample moment arrives, he walks through the office tallying the various activities. As each person is tallied he is checked off on the control record. If the recorder is not sure what an employee is doing, he asks him. He tallies an employee wherever the employee is first encountered. He does not postpone or avoid empty desks or persons on the telephone or conducting an interview. If the employee is not at his desk, has not yet been tallied, and is not out of the office, the recorder looks around for him and tallies him wherever he is, if visible. If he is nowhere visible, a special tally is made. Special tallies are also made for employees out of the office. After the first day or two, when the novelty has worn off, the entire office staff can be tallied silently and quickly, with practically no interference in office routine. In very large offices more than one recorder is used. At the end of the day the recorder enters on the mark sense card certain heading information, including time spent on leave during the day for all persons in that position-type. The recorder tallies himself by a special procedure which properly allows for the time spent on the work sampling project in the sample offices. All cards and control records are anonymous. The recorder spends an average of about $1\frac{1}{2}$ hours a day on the project.

For the self-reporting time-divisions, the employees also use mark sense cards. The self-reporter "checks out" with the recorder, enters his check-out time in a heading box, and also enters the time 20 minutes after his "check-out" time. This is his first sample moment. At that time he tallies his activity and enters the time one hour later. This is his next sample moment. He tallies his activity each hour throughout his self-reporting period. If he continues working into another time-division he starts a new card. The cards do not contain his name.

The procedure minimizes the active involvement of all employees except the recorder. About 80 percent of the employees, whose time is spent almost entirely in the office on regular time, are not actively involved at all. The remainder are involved only to the extent of filling out self-reporting cards. The procedure assumes that activities are reported accurately to the recorder. All

documents are anonymous, most of them containing pooled information for several persons in a position-type. The training emphasizes the anonymity of the reports and the purely statistical character of the data. The procedure has been welcomed almost universally as more scientific than previous time studies, and an atmosphere of confidence has been established. This atmosphere, plus careful analysis of consistency, plus comparison with past and present empirical data, have convinced us that the reports are generally accurate.

## CENTRAL OFFICE PROCESSING

The forms have been designed to make processing largely non-manual. All of the information necessary for tabulation is contained on the mark sense card except actual number of units produced. These are obtained from regular weekly reports from the district offices. Each time a new set of offices enters the sample several "dry-run" days are thoroughly edited by hand. Error sheets are sent to the district office. The first week of the regular run is similarly edited. From the second week on, the edit is handled mostly by electronic computer. Every card is intensively checked for consistency within itself and in relation to the other cards coming from the office. Minor errors are by-passed but printed out for analysis. Major errors cause a record rejection. Rejected records are corrected or adjusted, and a correction tape is constructed which adjusts the main tape. Tabulation is made monthly, quarterly, and cumulatively.

## ESTIMATES

For the sake of simplicity in the formulas that follow, we adopt the following symbols for the strata:

$A$ = Regions
$B$ = Size Groups
$C$ = Position Types
$D$ = Time Divisions

Only a single summation sign is used, although the summation may be over more than one stratum. For example: $\sum_{CD} x$ means that $x$ is summed over time divisions and position types. In the formulas below all symbols, except the foregoing, refer to a single ultimate stratum—one region, one size group, one position type, and one time division.

### TIME SPENT ON AN ACTIVITY

There are two levels of sampling within each ultimate stratum—a sample of district offices, and a sample of instants of time within the selected district office. Consequently, the estimate of time spent on an activity is made in two stages. First, the time spent in the selected district office is estimated. This estimate is then inflated to a stratum total.

Let

$x$ = number of tallies recorded for Activity $A$ in one district office in the tabulation period. This is a random variable.

$t$ = total number of tallies recorded in the district office in the tabulation period. This is not a random variable.

Then $p = x/t$ is an unbiased estimate of the proportional amount of time spent on Activity $A$ in the given position-type and time-division in one district office in the tabulation period (usually one month).

Let

$N$ = total amount of time spent in the position-type and time-division in the tabulation period in one district office. This is obtained from records kept by the recorder on the control record. It is not a random variable within the sample office.

Then $Np$ is an unbiased estimate of the time spent on Activity $A$ in the selected district office.

Let

$M$ = number of district offices in the ultimate stratum.
$m$ = number of district offices in the sample in the same ultimate stratum.
$do$ = abbreviation for district office.

Then

$$\frac{M}{m}\sum_{do}^{m} Np$$

is an unbiased estimate of the time spent on Activity $A$ in the ultimate stratum. A national estimate of time spent on Activity $A$ is given by adding this estimate over all strata

$$\sum_{\substack{A\ B\\ C\ D}} \frac{M}{m}\sum_{do}^{m} Np$$

The stratum additions can of course be made in any order.

### PROPORTIONAL TIME SPENT ON AN ACTIVITY, AND AVERAGE UNIT TIME SPENT PER UNIT OF PRODUCTION

An unbiased estimate of total time spent in a single ultimate stratum is given by

$$\frac{M}{m}\sum_{do}^{m} N.$$

Hence, the estimated proportional time spent on Activity $A$ is given by

$$\frac{\frac{M}{m}\sum_{do}^{m} Np}{\frac{M}{m}\sum_{do}^{m} N} = \frac{\sum_{do}^{m} Np}{\sum_{do}^{m} N}$$

$M$, $m$ are constant for all position-types and time-divisions, but vary in different regions and size groups. Hence,

a national estimate of proportional time spent on Activity $A$ is given by:

$$\frac{\sum_{AB} \frac{M}{m} \sum_{CD} \sum_{do}^{m} Np}{\sum_{AB} \frac{M}{m} \sum_{CD} \sum_{do}^{m} N}$$

It should be noted that the foregoing formulas for estimated proportion of time spent on Activity $A$ are ratios of random variables and are slightly biased, i.e., their mathematical expectation is not exactly equal to the true ratio being estimated. (Some very simple types of ratio estimates are unbiased.) For some strata combinations it would be possible to estimate the proportional time spent on Activity $A$ by using as a denominator the total time spent in *all* district offices, not inflating from the sample offices. Such a proportion would be strictly unbiased. However, the ratio estimate has advantages which tend to outweigh its disadvantage of being slightly biased. First, such a proportion can be calculated solely from the mark sense cards used in the project, thus dispensing with other records. Second, being obtained from the work sampling card alone, it is determinable for every stratum separately, including the four time divisions. Since our regular administrative reports do not provide information on time spent in the office and out of the office separately, the sample district offices provide the only source for such information. Third, this type of estimate tends to have smaller sampling variability. The reason for this will be made clear in the remarks on sampling variability.

In a similar way average unit time for a measurable activity is calculated. Let $w$ be the number of units of production of measurable activity $A$ in a single sample district office over the tabulated period. This is not a random variable. Workload cannot be established for position-types and time-divisions separately, since different kinds of persons working in various time divisions contribute to the finished product. Thus, average unit time spent on Activity $A$ cannot be given for separate position types and time divisions. For a single sample district office the estimated average time required to produce a unit of measurable Activity $A$ is given by

$$\frac{\sum_{CD} Np}{w}.$$

The estimated average unit time for Activity $A$ in a single region and size group is given by

$$\frac{\frac{M}{m} \sum_{do}^{m} \sum_{CD} Np}{\frac{M}{m} \sum_{do}^{m} w} = \frac{\sum_{do}^{m} \sum_{CD} Np}{\sum_{do}^{m} w}$$

The estimated average unit time for Activity $A$ nationally is given by

$$\frac{\sum_{AB} \frac{M}{m} \sum_{do}^{m} \sum_{CD} Np}{\sum_{AB} \frac{M}{m} \sum_{do}^{m} w}$$

EXAMPLE

Since there are hundreds of strata in this project, all examples will be simplified by ignoring the regions, and by assuming that there are only three size-groups. There are then 72 strata—6 position-types, 4 time divisions, and 3 size-groups. Consider one sample district office in the ultimate stratum "position-type claims representatives, time division in-office regular workday, size-group-3." In the tabulation month claims representatives spent a total of $N = 34{,}170$ minutes in regular time inside this office. The project recorded a total of $t = 402$ tallies for these persons inside the office during the regular work day in the tabulation month, of which 28 were on Activity $A$. Consequently the estimated amount of time spent by claims representatives in this office on Activity $A$ during the month was

$$Np = N \frac{x}{t} = (34{,}170) \frac{28}{402} = 2380.0 \text{ minutes.}$$

There were $m = 48$ district offices in the sample from size-group-3 during this month. A similar calculation was made for each of these sample offices and the sum obtained. This was

$$\sum_{do}^{48} Np = \begin{matrix} 65{,}275 \text{ minutes or} \\ 1087.9 \text{ hours} \end{matrix}$$

There were $M = 326$ size-group-3 district offices altogether. Consequently, the estimated time spent by claims representatives on Activity $A$ during in-office regular time in size-group-3 offices was

$$\frac{M}{m} \sum_{do}^{48} Np = \frac{326}{48} (1087.9) = 7221.0 \text{ hours.}$$

The total amount of time spent by claims representatives in the office during the regular work day in the 48 sample offices was 22,173 hours. Consequently the estimated proportional amount of time spent on Activity $A$ in the ultimate stratum was

$$\frac{\sum_{do}^{48} Np}{\sum_{do}^{48} N} = \frac{1087.9}{22{,}173} = .049064, \text{ or } 4.9\%.$$

Similar estimates of time spent on Activity $A$ were carried out for the remaining time divisions and position

types and added together. The result was an estimate of

$$\sum_{C}^{6}\sum_{D}^{4}\sum_{do}^{48} Np = 177{,}810$$

minutes spent on Activity $A$ in the sample size-group-3 district offices. These 48 offices had a total production of

$$\sum_{do}^{48} w = 24{,}809$$

Activity $A$ units in the tabulation period. Consequently, the estimated average unit time for activity $A$ in size-group-3 district offices in the tabulation period was

$$\frac{177{,}810}{24{,}809} = 7.2 \text{ minutes}$$

The calculations to obtain a national estimate of the proportion of time spent on Activity $A$ are summarized in Table 1.

TABLE 1

*Summary Calculations of National Estimate of Percent of Time Spent on Activity A*

(Columns 3–6 in hours)

| Size Group | $\frac{M}{m}$ | $\sum_{CD}^{m}\sum_{do} Np$ | $\sum_{CD}^{m}\sum_{do} N$ | $\frac{M}{m}\sum_{CD}^{m}\sum_{do} Np$ | $\frac{M}{m}\sum_{CD}^{m}\sum_{do} N$ |
|---|---|---|---|---|---|
| (1) | (2) | (3) | (4) | (5) | (6) |
| 1 | 8.1818 | 2,245.7 | 70,845 | 18,374 | 579,640 |
| 2 | 7.1000 | 1,870.4 | 58,246 | 13,280 | 413,550 |
| 3 | 6.7917 | 2,963.4 | 78,516 | 20,127 | 533,260 |
| Total | — | — | — | 51,781 | 1,526,450 |

$$\text{Estimated national proportion} = \frac{51{,}781}{1{,}526{,}450} = .0339 = 3.4\%.$$

## SAMPLING VARIABILITY

One of the major advantages of work sampling over classical time studies is that it is based on a precise statistical design, with estimates constructed by probability calculations. Consequently the sampling variability of the data can be estimated.

### VARIANCE OF THE ESTIMATE OF TIME SPENT ON AN ACTIVITY

The estimate is based on a stratified cluster sample. All of the district offices, or clusters, in a single ultimate stratum have the same chance of being drawn into the sample. Within each sample district office a random subsample of instants of time is selected. All instants of time have the same chance of being drawn into the sample. Since there are two components of sampling, the estimate of time spent on Activity $A$ in a single ultimate stratum has two components of sampling variability—the variability due to different possible samples of district offices, and the variability due to different possible samples of time instants within the selected district offices.

The first component is called the between-district office (or between-cluster) variability, symbolized by $\sigma_b^2$. The second component is called the within-district office (or within-cluster) variaiblity, symbolized by $\sigma_w^2$. In addition to the symbols already introduced, let

$P$ = true proportion of time spent on Activity $A$ in a single district office in the ultimate stratum.

$Q = 1 - P$

Then

$NP$ = true amount of time spent on Activity $A$ in the district office in the ultimate stratum.

$\overline{NP} = \frac{1}{M}\sum_{do}^{M} NP$ = Mean average amount of time spent on Activity $A$ per district office in the ultimate stratum.

The between-district office variance of amount of time spent on Activity $A$ in a single ultimate stratum is

$$\sigma_b^2 = \frac{M^2}{m}\,\frac{M-m}{M-1}\,\frac{1}{M}\sum_{do}^{M}(NP - \overline{NP})^2 \qquad \text{Eq. 1}$$

The within-district office variance is

$$\sigma_w^2 = \frac{M}{m}\sum_{do}^{M} N^2\,\frac{PQ}{t}\,^{1} \qquad \text{Eq. 2}$$

The total variance of the estimate of time spent on Activity $A$ in one ultimate stratum is

$$\sigma_{A'}^2 = \sigma_b^2 + \sigma_w^2 \qquad \text{Eq. 3}$$

Here the subscript $A'$ denotes the estimate of time spent on Activity $A$. (Wherever a symbol appears with a prime, it means an estimate of the quantity denoted by the same symbol without the prime. Thus $A'$ is an estimate of time spent on Activity $A$; $\sigma_{A'}^2$ is an estimate of $\sigma_{A'}^2$ etc.) The sample of district offices is from a finite universe of district offices, while the sample of time instants within the district office is from an infinite universe of time instants. This accounts for the presence of a finite correction factor in $\sigma_b^2$ and its absence in $\sigma_w^2$.

The variance for an estimate over several strata is simply the sum of the separate variances. Thus the variance of the national estimate of time spent on Activity $A$ is

$$\sum_{\substack{AB\\CD}} \sigma_{A'}^2 \qquad \text{Eq. 4}$$

Eq. 3 may be estimated from the sample. It can be estimated in more than one way. It is possible to estimate

[1] All persons working in the office during a regular work day are tallied about the same time. However for the purpose of variance calculation the tallies are assumed to be a simple random sample of all possible moments of time of all persons in the position type. $\sigma_w^2$ is thereby simplified to the variance of a simple random sample. Comparative investigations on the project have shown that the results obtained with the simplifying assumption are very close to those obtained by a more refined formula.

$\sigma_b^2$ and $\sigma_w^2$ separately. This is often very desirable, for it shows the separate impact on variability of selection of sample offices ($\sigma_b^2$) and sampling within the selected offices ($\sigma_w^2$). This knowledge enables a more rational determination of the number of offices to include and the number of tallies to be taken within the selected offices. However this paper presents a simpler formula $\sigma'^2_{A'}$ that estimates the total variation by a single expression. $p$ is an estimate of $P$, $Np$ is an estimate of $NP$, and

$$\overline{Np} = \frac{1}{m}\sum_{do}^{m} Np$$

is an estimate of $\overline{NP}$. We then have:

$$\sigma'^2_{A'} = \frac{M(M-m)}{m-1}\,\frac{1}{m}\sum_{do}^{m}(Np-\overline{Np})^2 \qquad \text{Eq. 5.}$$

This is a slightly biased estimate of $\sigma_{A'}^2$. Its mathematical expectation is

$$\frac{M^2}{m}\,\frac{M-m}{M-1}\,\frac{1}{M}\sum_{do}^{M}(NP-\overline{NP})^2 + \left(\frac{M}{m}-1\right)\sum_{do}^{M} N^2\,\frac{PQ}{t}.$$

This is slightly smaller than $\sigma_{A'}^2$. However, this under-estimate is considerably mitigated because in this project variability between district offices, $\sigma_b^2$, contributes far more to the total variance than the variability within district offices, $\sigma_w^2$. The under-estimate exists only for the within-district office variability. Hence, its impact is slight.

To estimate the variance $\sigma_{A'}^2$ over several strata Eq. 5. is simply added over the strata as in Eq. 4.

EXAMPLE

We will compute the sampling variability of the estimated total of 7,221 hours spent on Activity $A$ by claims representatives inside the office during the regular work day in size-group-3 offices in the tabulation month. From the previous example we have

$\sum_{do}^{48} Np = 1087.9$ hours. Hence

$$\overline{Np} = \frac{1}{48}\sum_{do}^{48} Np = \frac{1087.9}{48} = 22.664 \text{ hours.}$$

For the particular sample office in the previous example

$$Np = \frac{2380.0}{60} = 39.667 \text{ hours.}$$

Hence $(Np-\overline{Np})^2 = (17.003 \text{ hours})^2 = 289.10 \text{ hours}^2$. In like manner the squared differences can be obtained for all 48 sample district offices in this ultimate stratum. (Well-known algebraic shortcuts can of course be used.) Their sum is

$$\sum_{do}^{48}(Np-\overline{Np})^2 = 7458.8 \text{ hours}^2.$$

$$\frac{M(M-m)}{m-1}\,\frac{1}{m} = \frac{326(326-48)}{47(48)} = 40.172$$

Hence

$$\sigma'_{A'} = \sqrt{(40.172)(7458.8)} = 547 \text{ hours.}$$

Thus the estimate of 7221 hours has a standard error of 547 hours. A more convenient expression is the estimated coefficient of variation $V'_{A'}$ as an expression of relative sampling variability.

$$V'_{A'} = \frac{\sigma'_{A'}}{\frac{M}{m}\sum_{do}^{m} Np} = \frac{547 \text{ hours}}{7221 \text{ hours}} = 7.6\%$$

VARIANCE OF PROPORTION OF TIME SPENT ON AN ACTIVITY

The proportion of time spent on Activity $A$ in an ultimate stratum is a ratio estimate,

$$\frac{\frac{M}{m}\sum_{do}^{m} Np}{\frac{M}{m}\sum_{do}^{m} N} = P'$$

Both numerator and denominator are subject to sampling variability. The general formula for the variance of an estimate which consists of the ratio of two unbiased estimates involves the correlation between these two random variables. The variance may be expressed in several ways. The simplest expression may be stated as follows. In addition to definitions already stated, let

$\sum_{do}^{M} NP$ = true amount of time spent on Activity $A$ in an ultimate stratum.

$\sum_{do}^{M} N$ = true total amount of time spent in the same ultimate stratum.

$\overline{N} = \frac{1}{M}\sum_{do}^{M} N$ = true mean average amount of total time spent per district office in the ultimate stratum.

$N' = \frac{M}{m}\sum_{do}^{m} N$ = the unbiased estimate of total time spent in a single ultimate stratum, as stated previously.

$$\sigma^2_{N'} = \frac{M^2}{m}\,\frac{M-m}{M-1}\,\frac{1}{M}\sum_{do}^{M}(N-\overline{N})^2 \qquad \text{Eq. 6.}$$

= variance of the estimate of total time spent in the ultimate stratum. This is the same as Eq. 1., reflecting the between-district office variability in total time spent. This is the only level of sampling for total time spent. The variance has no within-district office component. Therefore, this is also the analogue of Eq. 3. for total time spent in the ultimate stratum.

$$\sigma_{A'N'} = \frac{M^2}{m}\,\frac{M-m}{M-1}\,\frac{1}{M}\sum_{do}^{M}(NP-\overline{NP})(N-\overline{N}) \quad \text{Eq. 7.}$$

= Covariance between the estimate of time spent and the

$$A' = \frac{M}{m}\sum_{do}^{m} Np \text{ on activity } A,$$

estimate of total time spent

$$N' = \frac{M}{m}\sum_{do}^{m} N$$

in the ultimate stratum. The covariance in effect measures the correlation between the two estimates. We will have more to say about it.

$$V^2_{A'} = \frac{\sigma_{A'}^2}{\left(\sum_{do}^{M} NP\right)^2}$$

$$V^2_{N'} = \frac{\sigma_{N'}^2}{\left(\sum_{do}^{M} N\right)^2}$$

Squared coefficients of variation of the two estimates; called the "rel-variance" because they measure the relative variability.

$$V_{A'N'}\ \frac{\sigma_{A'N'}}{\left(\sum_{do}^{M} NP\right)\left(\sum_{do}^{M} N\right)} = \text{The "rel-covariance".}$$

It is frequently more meaningful to express sampling variability in relative rather than absolute terms. For example, if it is estimated that, say, 50,000 hours were spent on an activity, it is often more useful to say that the variability of this estimate is, say, 5%, than to say that it is 2,500 hours. The relative variability is usually expressed as the coefficient of variation, and its square as the rel-variance, and this is how we will express the variability of the proportion of time spent on Activity $A$. The simplest expression of the rel-variance of the estimated proportion $P'$ is

$$V^2_{P'} = V_{A'}^2 + V_{N'}^2 - 2V_{A'N'}$$

$$= \frac{\sigma_{A'}^2}{\left(\sum_{do}^{M} NP\right)^2} + \frac{\sigma_{N'}^2}{\left(\sum_{do}^{M} N\right)^2} - 2\frac{\sigma_{A'N'}}{\left(\sum_{do}^{M} NP\right)\left(\sum_{do}^{M} N\right)} \quad \text{Eq. 8.}$$

$$V^2_{P'} = \frac{\text{Eq. 3.}}{\left(\sum_{do}^{M} NP\right)^2} + \frac{\text{Eq. 6.}}{\left(\sum_{do}^{M} N\right)^2} - 2\frac{\text{Eq. 7.}^{2}}{\left(\sum_{do}^{M} NP\right)\left(\sum_{do}^{M} N\right)} \quad \text{Eq. 9.}$$

As before, Eq. 9. may be estimated from the sample itself. The estimate is obtained by replacing each term in it by an unbiased estimate, as exhibited in the following table.

| *True value* | *Unbiased estimate* |
|---|---|
| Eq. 3. | $\sigma'^2_{A'}$ = Eq. 5. (slightly biased) |
| Eq. 6. | $\sigma'^2_{N'} = \frac{M(M-m)}{m-1}\,\frac{1}{m}\sum_{do}^{m}(N-\overline{N}')^2$ |
| Eq. 7 | $\sigma'_{A'N'} = \frac{M(M-m)}{m-1}\,\frac{1}{m} \cdot \sum_{do}^{m}(Np-\overline{Np})(N-\overline{N}')$ |
| $\sum_{do}^{M} NP$ | $\frac{M}{m}\sum_{do}^{m} Np$ |
| $\sum_{do}^{M} N$ | $\frac{M}{m}\sum_{do}^{m} N$ |
| $\overline{N}$ | $\overline{N}' = \frac{1}{m}\sum_{do}^{m} N$ |

If the estimates are put into Eq. 9. and simplified, we have from the sample an estimate of the rel-variance of the proportional amount of time spent on Activity $A$ in a single ultimate stratum.

$$V'^2_{P'} = \frac{m}{M}\,\frac{M-m}{m-1}\left[\frac{\sum_{do}^{m}(Np-\overline{Np})^2}{\left(\sum_{do}^{m} Np\right)^2} + \frac{\sum_{do}^{m}(N-\overline{N}')^2}{\left(\sum_{do}^{m} N\right)^2} - 2\frac{\sum_{do}^{m}(Np-\overline{Np})(N-\overline{N}')}{\left(\sum_{do}^{m} Np\right)\left(\sum_{do}^{m} N\right)}\right] \quad \text{Eq. 10.}$$

EXAMPLE

The proportional amount of time spent on Activity $A$ by claims representatives inside the office during the regular work day in size-group-3 offices in the tabulation

[2] Eq. 9. is an approximation. First, it is the first three terms in an infinite series; second, it is not strictly a relative variance but a relative "mean square error," because the estimate of proportional time spent on Activity $A$ is not strictly unbiased.

TABLE 2

*Summary Calculation of the Relative Standard Error of National Percent of Time Spent on Activity A—Eq. 11*

| (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) | (9) |
|---|---|---|---|---|---|---|---|---|
| Size | $M$ | $m$ | $\frac{M(M-m)}{(m-1)m}$ | $\frac{M(M-m)}{(m-1)m}\sum_{C}\sum_{D}\sum_{do}^{48}(Np-\overline{Np})^2$ | $\frac{M(M-m)}{(m-1)m}\sum_{C}\sum_{D}\sum_{do}^{48}(N-\overline{N}')^2$ | $\frac{M(M-m)}{(m-1)m}\sum_{C}\sum_{D}\sum_{do}^{48}(Np-\overline{Np})(N-\overline{N}')$ | $\frac{M}{m}\sum_{C}\sum_{D}\sum_{do}^{48}Np$ | $\frac{M}{m}\sum_{C}\sum_{D}\sum_{do}^{48}N$ |
| Group | | | | hours$^2$ | hours$^2$ | hours$^2$ | hours | hours |
| 1 | 90 | 11 | 64.636 | 4,410,800 | $262{,}480\times10^4$ | $756{,}490\times10^2$ | 18,374 | 579,640 |
| 2 | 142 | 20 | 45.589 | 788,250 | $20{,}735\times10^4$ | $76{,}299\times10^2$ | 13,280 | 413,550 |
| 3 | 326 | 48 | 40.172 | 715,790 | $11{,}352\times10^4$ | $41{,}315\times10^2$ | 20,127 | 533,260 |
| $\Sigma$ | — | — | — | 5,914,800 | $294{,}570\times10^4$ | $874{,}100\times10^2$ | 51,781 | $15{,}264\times10^2$ |

$$V'^2_{A'} = \frac{\sum \text{Col. 5}}{(\sum \text{Col. 8})^2} = .0022059 \qquad P' = \frac{A'}{N'} = \frac{\sum \text{Col. 8}}{\sum \text{Col. 9}} = 3.4\%$$

$$V'^2_{N'} = \frac{\sum \text{Col. 6}}{(\sum \text{Col. 9})^2} = \frac{.0012643}{.0034702} \qquad V'_{P'} = 3.6\%$$

$$-2V'_{A'N'} = -2\frac{\sum \text{Col. 7}}{(\sum \text{Col. 8})(\sum \text{Col. 9})} = \frac{-.0022118}{}$$

$$V'^2_{P'} = .0012584$$

$$\sqrt{V'^2_{A'} + V'^2_{N'}} = .0589$$

$$V'_{A'} - V'_{N'} = \frac{.0115}{.0704/2}$$

$$V''_{P'} = .0352 = 3.5\%$$

month was estimated previously as 4.9%. We shall obtain the coefficient of variation of this percentage. From the previous examples, we have

$$\sum_{do}^{48}(Np - \overline{Np})^2 = 7458.8 \text{ hours}^2$$

$$\sum_{do}^{48} Np = 1087.9 \text{ hours}$$

$$\overline{Np} = 22.664 \text{ hours}$$

$$\sum_{do}^{48} N = 22{,}173 \text{ hours}$$

whence

$$\overline{N}' = \frac{1}{48}\sum_{do}^{48} N = \frac{1}{48}(22{,}173 \text{ hours}) = 461.94 \text{ hours}.$$

For the particular sample district office in the first example we have

$$N = \frac{34{,}170}{60} = 569.50 \text{ hours}$$

$$Np = \frac{2380.0}{60} = 39.667 \text{ hours}$$

$$(N - \overline{N}')^2 = (107.56 \text{ hours})^2 = 11{,}569 \text{ hours}^2$$

$$(Np - \overline{Np})(N - \overline{N}') = (17.003 \text{ hours})(107.56 \text{ hours}) = 1828.8 \text{ hours}^2.$$

In like manner we compute $(N-\overline{N}')^2$, $(Np-\overline{Np})(N-\overline{N}')$ for all 48 sample district offices, and obtain

$$\sum_{do}^{48}(N - \overline{N}')^2 = 830{,}750 \text{ hours}^2$$

$$\sum_{do}^{48}(Np - \overline{Np})(N - \overline{N}') = 32{,}914 \text{ hours}^2$$

$$\frac{m}{M}\frac{(M-m)}{m-1} = \frac{48(326-48)}{326(47)} = .87090$$

We then have Eq. 10.

$$V'^2_{P'} = (.87090)\left[\frac{7458.8 \text{ hours}^2}{(1087.9 \text{ hours})^2} + \frac{830{,}750 \text{ hours}^2}{(22{,}173 \text{ hours})^2} - 2\frac{32{,}914 \text{ hours}^2}{(1087.9 \text{ hours})(22{,}173 \text{ hrs.})}\right]$$

$$= .0045806$$

$V'_{P'} = .06768$, or 6.8%.

Thus the estimate of 4.9% has a relative standard error of about 6.8%. To convert this to a percentage point standard error, we merely recall that

$$\frac{\sigma'_{P'}}{P'} = V'_{P'}.$$

Hence $\sigma'_{P'} = (.068)(.049) = .0033$. Thus

4.9% ± .33% is a one-sigma confidence interval.

In obtaining the variance for proportional time spent on Activity $A$ for more than one size-group, the finite correction factors and inflators cannot be factored out because they vary with region and size-group. For a national estimate of proportional time spent on an activity, the rel-variance starts as usual with the general Eq. 8 for $V^2_{P'}$, and reduces by substitution of the estimates shown previously to the estimating form:

$$V'^2_{P'} = \frac{\sum_{AB}\frac{M(M-m)}{(m-1)m}\sum_{CD}\sum_{do}^{m}(Np - \overline{Np})^2}{\left(\sum_{AB}\frac{M}{m}\sum_{CD}\sum_{do}^{m} Np\right)^2}$$

$$+\frac{\sum_{AB}\frac{M(m-m)}{(m-1)m}\sum_{CD}\sum_{do}^{m}(N-\overline{N}')^2}{\left(\sum_{AB}\frac{M}{m}\sum_{CD}\sum_{do}^{m}N\right)^2}$$

$$-2\frac{\sum_{AB}\frac{M(M-m)}{(m-1)m}\sum_{CD}\sum_{do}^{m}(Np-\overline{Np})(N-\overline{N}')}{\left(\sum_{AB}\frac{M}{m}\sum_{CD}\sum_{do}^{m}Np\right)\left(\sum_{AB}\frac{M}{m}\sum_{CD}\sum_{do}^{m}N\right)} \qquad \text{Eq. 11.}$$

Illustrative calculations for the relative variability of the national estimate of Activity $A$ in our running example are summarized in Table 2 (recall that we are ignoring regions in the example).

*(Text continued in next column)*

### VARIANCE OF AVERAGE MINUTES PER UNIT OF PRODUCTION

The general form of the rel-variance is the same as Eq. 8., with $N'$ replaced by

$$W' = \frac{M}{m}\sum_{do}^{m} w,$$

the estimate of the number of units of Activity $A$ produced in the tabulation month. Since workload cannot be separated by position type or time division, $W'$ is an estimate over these strata in a single region and size-group. As before, Eq. 8. is estimated for a single region and size-group from the sample with the following unbiased estimates.

| *True value* | *Unbiased estimate* |
|---|---|
| $\sigma^2_{A'}$ | $\sigma'^2_{A'} = \frac{M(M-m)}{m-1}\frac{1}{m}\left(\sum_{do}^{m}\sum_{CD}Np - \frac{1}{m}\sum_{do}^{m}\sum_{CD}Np\right)^2$ (slightly biased) |
| $\sigma^2_{W'}$ | $\sigma'^2_{W'} = \frac{M(M-m)}{m-1}\frac{1}{m}\sum_{do}^{m}\left(w - \frac{1}{m}\sum_{do}^{m}w\right)^2$ |
| $\sigma_{A'W'}$ | $\sigma'_{A'W'} = \frac{M(M-m)}{m-1}\frac{1}{m}\sum_{do}^{m}\left(\sum_{CD}Np - \frac{1}{m}\sum_{do}^{m}\sum_{CD}Np\right)\left(w - \frac{1}{m}\sum_{do}^{m}w\right)$ |
| $\sum_{do}^{M}NP$ | $\frac{M}{m}\sum_{do}^{m}\sum_{CD}Np$ |
| $\sum_{do}^{M}w$ | $W' = \frac{M}{m}\sum_{do}^{m}w$ |

If these unbiased estimates are put in Eq. 8., we have the rel-variance estimating equation for a single region and size-group, similar to Eq. 10.

$$V'^2_{s'} = \frac{m}{M}\frac{M-m}{m-1}\left[\frac{\sum_{do}^{m}\left(\sum_{CD}Np - \frac{1}{m}\sum_{do}^{m}\sum_{CD}Np\right)^2}{\left(\sum_{do}^{m}\sum_{CD}Np\right)^2} + \frac{\sum_{do}^{m}\left(w - \frac{1}{m}\sum_{do}^{m}w\right)^2}{\left(\sum_{do}^{m}w\right)^2} - 2\frac{\sum_{do}^{m}\left(\sum_{CD}Np - \frac{1}{m}\sum_{do}^{m}\sum_{CD}Np\right)\left(w - \frac{1}{m}\sum_{do}^{m}w\right)}{\left(\sum_{do}^{m}\sum_{CD}Np\right)\left(\sum_{do}^{m}w\right)}\right] \qquad \text{Eq. 12.}$$

Here $s'$ denotes the estimate of average time per unit of production. Similarly, for the variance of average unit time on Activity $A$ nationally we may write the analogue of Eq. 11., expanding the summations in Eq. 12. Since the calculations are essentially the same as those illustrating Eq. 10. and Eq. 11., no example will be given.

### REMARKS ON SAMPLING VARIABILITY FORMULAS

The covariance between two unbiased estimates $u'$, $v'$, has the following relationship to the correlation between the two estimates:

$$\sigma_{u'v'} = r_{u'v'}\sigma_{u'}\sigma_{v'}$$

In most ratio estimates used in practice, and certainly in this project, the correlation between the numerator and denominator is positive. Since the covariance enters negatively into Eq. 8., it is clear that the higher the correlation the greater is the gain in statistical efficiency by using the ratio estimate. On the other hand if the correlation is low the ratio estimate may be less efficient than an unbiased estimate, whose rel-variance is given by the first term of Eq. 8. In our project ratio estimates of proportional time spent on Activity $A$ are used not primarily in order to increase statistical efficiency, but, first because they eliminate using additional administrative records, and second, because we can obtain information on total time spent for certain strata only from the sample. For these strata we must use ratio estimates.

The calculation of the covariance can become quite burdensome. Assuming a positive correlation between numerator and denominator, a shortcut can be adopted which eliminates the covariance term. This consists of setting $r$ equal to 1 and obtaining the minimum standard error; then setting $r$ equal to 0 and obtaining the maximum standard error; then averaging the maximum and minimum standard errors. Thus for proportional time spent on Activity $A$ we have, from Eq. 8.

$$V^2_{P'} = V^2_{A'} + V^2_{N'} - 2r_{A'N'}V_{A'}V_{N'}$$

Minimum relative standard error, $r = 1$.

$$V_{P'} = \sqrt{V^2_{A'} + V^2_{N'} - 2V_{A'}V_{N'}} = V_{A'} - V_{N'}$$

Maximum relative standard error $r = 0$.

$$V_{P'} = \sqrt{V^2_{A'} + V^2_{N'}}$$

*Example:* Table 2 inset exhibits the calculations for the relative standard error of national estimate of proportional time spent on Activity $A$. The relative standard error $V'_{P'} = 3.5\%$ so obtained is almost identical with the value $V'_{P'} = 3.6\%$ obtained by the more complete formula. It should not be supposed that such close similarity always, or even often, obtains.

There are two very important additional areas in a complete program of variability calculation which space limitation forbids our discussing in detail.

In some cases the stratification is so fine that only one cluster is drawn into the sample from some strata. In these cases formulas $\sigma'^2_{A'}$, $\sigma'^2_{N'}$, $\sigma'^2_{W'}$, $\sigma'_{A'N'}$, $\sigma'_{A'W'}$ are inapplicable, since it is not possible to estimate sampling variability from a sample of one. There are two ways in which this difficulty is usually overcome.

1. If the clusters are very similar to each other, the sample within the stratum may be treated not as a single cluster, but as a simple random sample of ultimate sampling units over the whole stratum.
2. Several strata can be "collapsed," for variance estimation, to create a single "pseudo-stratum" containing more than one cluster. The foregoing formulas are applied to the "pseudo-stratum."

All variance formulas apply only to a single activity. The calculation of sampling variability for all estimates can become quite burdensome. This is often overcome by selecting a sub-group of activities whose values range from small to large, obtaining the sampling variability of these, constructing a scattergram, and fitting a curve to the scattergram. The curve yields an "average" or "typical" sampling error for any activity of specified size. Variability is then stated in "average" terms depending only on the size of the activity, independent of what the activity is.

## SUMMARY

The method of work sampling has been applied successfully to a nationwide field organization that carries on a wide variety of activities both inside and outside the field offices. The method has resulted in obtaining reliable estimates of nearly two dozen measurable and non-measurable activities. The size of the organization, the complexity of data desired, and various other administrative and statistical considerations have led to the utilization of some of the more sophisticated techniques of the theory of sample surveys in the statistical design. From each of several hundred strata, clusters have been selected with equal probability. Within each selected cluster a sample of instants of time has been selected, also with equal probability. The estimates are of total time spent on an activity, proportions of time spent, and average unit time spent on an activity. The sampling variability formulas reflect the different estimates. The project has been so constructed that all necessary information except production data is contained on mark-sense cards, thus minimizing the coordination of different documents. The edit and processing procedures are almost entirely mechanical. The method is statistically more valid and reliable than classical time studies, much simpler, less time-consuming and less costly to operate, and inspires genuine confidence by the field staff in the accuracy of the results. The method provides data for a wide variety of management uses.

## REFERENCES

(1) Barnes, Ralph M. *Work Sampling*, Wm. C. Brown, Co., Dubuque, Iowa, 1956.
(2) Cochran, W. G., *Sampling Techniques*, John Wiley and Sons, New York, 1953. Chapter 11.
(3) Deming, W. E., *Some Theory of Sampling*, John Wiley and Sons, New York, 1950. Chapters 5 and 10.
(4) Hansen, M. H., Hurwitz, W. N., and Madow, W. G., *Sample Survey Methods and Theory*, 2 Vols., John Wiley and Sons, New York, 1953.

# Simulation as a Production Aid

*by* JOHN L. COLLEY, JR.

*Department of Industrial Administration, School of Engineering, Yale University*

THE following is a description of how simulation led an Industrial Engineer to the correct solution of an unusual production problem. Simulation was not the answer in itself, but it pointed the way to an adequate problem solution. It is believed that others might be interested in this problem since there are a large number of similar types to which the same general approach should be useful. The author encountered the problem while employed by the Western Electric Company at its Burlington, North Carolina plant, during the summer of 1958.

Where simulation is usually thought of in terms of high speed electronic computers, this application involves only the use of a desk calculator. Less than half a day was involved in the study from initial contact with the problem, through the simulation process, to the final conclusions.

## OUTLINE OF THE PROBLEM

The problem involved trouble which was being experienced in the shop in the assembly of an electronic component. For the assembly to function, part 1 always had to be smaller than part 2. Yet the lower specification limit set by design engineers on part 2 was less than the nominal size specified for part 1. The shop had begun to assemble the first run of the components and a large percentage (between 30 and 40 percent) were failing to mate properly. The shop people were certain that the overlapping specification limits were the real culprits and readily blamed the design people for the difficulty.

It was decided that the first step in analyzing the problem should be to determine to what extent the design specifications were in error. Stated another way, under the conditions of current product design, what percentage of the parts would normally be expected to fail to mate under ordinary conditions? By considering the nominal dimensions for each part and the upper and lower specification limits as measures of dispersion, tables of random normal deviates could be used to simulate the choosing of the two parts at random as in the assembly operation and the process could be tested over a large number of assemblies in a rather short time.

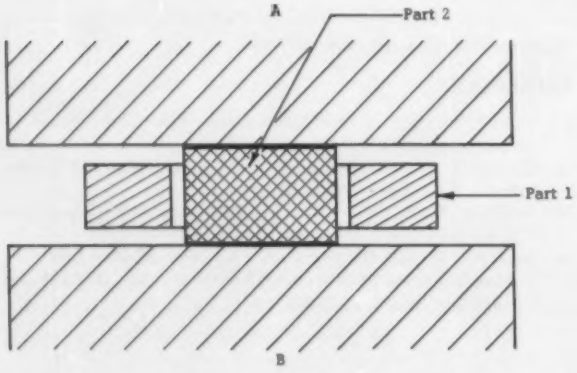



FIG. 1. Assembly of Parts 1 and 2 between Surfaces A and B.

## DESCRIPTION OF PRODUCTION PROCESS

Because of the nature of the work (defense-electronics), the actual parts in question cannot be shown. But, Figure 1 indicates their general characteristics.

Imagine that between surfaces A and B, a spacer is placed. The spacer is called part 2. It is desired that the ring, part 1, which fits around the spacer, will be loose and free to move. It is necessary that the ring not be wedged tightly between the two surfaces. Since there are other reasons for desiring part 1 to be as thick as possible, the relative thicknesses of parts 1 and 2 in any given assembly are extremely important. Assuming then that there is considerable expense if part 1 is as thick as or thicker than part 2 and it is also desirable that part 1 be as thick as possible, how should the manufacturing specifications for the two parts have been set?

The manufacturing information showed the nominal size of part 1 to be $.057 \pm .005$ and part 2 to be $.062 \pm .006$. For the sake of analysis, it was logical to assume that the nominal values together with the tolerance spreads could be assumed to define a characteristic normal population of each of the two parts. The production facility making part 1, for instance, should have been set for the nominal dimension and as long as variation about the nominal remained within three standard deviations of the intended value, no process corrections should have been made. It would have been fundamentally uneconomical to try to refine the process beyond the 6 standard deviation band of normal chance variation. This band about the nominal was built into the manufacturing facility itself. Searching for assignable causes inside the area of expected random fluctuation would have been literally chasing rainbows.

It was logical, then, to assume in this instance that parts 1 and 2, as they were found in bins at the assembly station, comprised normal populations with mean ap-

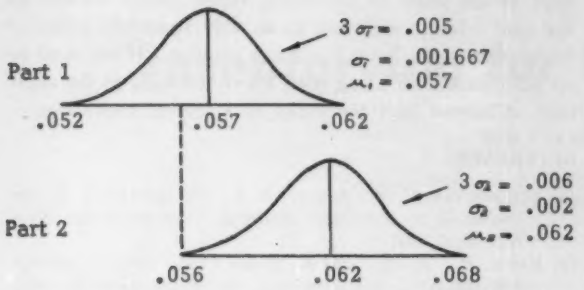



FIG. 2. Dimensional Variation of Parts 1 and 2.

proximately equal to the desired nominal dimensions and three-sigma limits equal to the specified upper and lower tolerance limits. This reasoning leads to the representation, shown in Figure 2, of the populations of the two parts as they came together at the work station for assembly.

If the difference between the upper three-sigma limit and the mean value for part 2 is .006, then sigma ($\sigma_2$) must be .002. This same reasoning shows $\sigma_1$ to be .001667. The populations of the two parts at the assembly station are considered to be defined by the means and standard deviations derived from the design tolerances.

At this stage the problem was to determine whether the high incidences of failure to mate at assembly were caused by the designed overlapping of the populations. It was decided that since direct mathematical calculation of the probability of two parts chosen at random mating properly would be very difficult, simulation of the assembly by a Monte Carlo technique would be the most expeditious approach.

## THE SIMULATION PROCESS

It was decided that the next step in analyzing the problem should be to determine to what extent the design specifications were in error. Stated another way, under correct conditions of product design, what percentage of the parts would normally be expected to fail to mate in assembly.

As mentioned, the nominal dimension might be assumed to represent the measure of central tendency of a normal distribution and the extreme values or limits might represent the natural dispersion of a distribution. With this representation, tables of random normal deviates could be used to simulate the choosing of the two parts at random as in the assembly operation. The process could thus be tested over a large number of simulated assemblies in a rather short time.

The procedure used for the simulation was as follows:

1. A data sheet was drawn with columns for random normal deviates corresponding to each of the parts, columns for the random deviates converted to part sizes in terms of the part parameters, and a place for indication of whether or not the assembly would have been functional.
2. A random deviate was chosen from a table of random normal deviates and translated into a part size for part 1 using the parameters specified by design.
3. The same procedure was repeated for part 2.
4. The results of the two steps outlined were compared to determine if the assembly would have been functional.
5. This process was carried on for a period of two and a half hours, during which 200 assemblies were simulated. Part of these are shown in Table 1.

The occurrence of failures was found to be negligible. An examination of the specifications reveals that the likelihood of a small 2 in conjunction with a large 1 should be small. If the object of the study was to determine the likely percentage of failures to mate, many more repetitions of the simulation process would have been necessary. In this instance the primary concern of the production people was to uncover the cause for the production bottleneck. As soon as the simulation showed that the basic design was not the real trouble, the attentions of the investigation were brought to bear on other aspects of the problem.

## RESULTS AND CONCLUSIONS

A consideration of the materials from which the two parts were made led to the next step in the inquiry. Part 1 was made of plastic in a continuous molding process and the die characteristics would probably assure their uniformity. Part 2 was made of sheet steel of a certain grade and size. It was decided to check some of the 2 parts at random in order to find any variation from specification limits which might be present. A check of some of the parts revealed a distribution of sizes far different from that described by the sheet steel specification sizes. The thicknesses were all above the lower dimension so no failure to meet specification was discovered. The central value, however, was much nearer to the lower limit than the mid-value of the grade size and the dispersion was quite narrow. It was concluded after checks of different lots, sheets, and locations within sheets revealed the same pattern of thicknesses that a design change would be necessary. The material for part 2 had to be changed to a next higher sheet size.

This study of the assembly operation by simulation

TABLE 1

| | Part 1 | | Part 2 | | Assembly |
|---|---|---|---|---|---|
| Assembly No. | Random Dev. | Part Size | Random Dev. | Part Size | Good or Bad |
| 1 | −0.513 | .056145 | −0.068 | .061864 | G |
| 2 | −1.055 | .055242 | 0.543 | .063086 | G |
| 3 | −0.488 | .056187 | 0.926 | .063852 | G |
| 4 | 0.756 | .058260 | 0.571 | .063142 | G |
| 5 | 0.225 | .057375 | 2.945 | .067890 | G |
| 6 | 1.677 | .059795 | 0.881 | .063762 | G |
| . | . | . | . | . | . |
| . | . | . | . | . | . |
| . | . | . | . | . | . |
| . | . | . | . | . | . |
| . | . | . | . | . | . |

brought out an interesting bit of information useful to designers in the future. The steel manufacturers or sheet producers are obviously able to control the thicknesses of the sheet much more closely than when the specification limits for the various standard sizes were set. This probably is due to more accurate electronic and nuclear controls used to regulate the manufacturing process. Designers must, in any case, beware of standard size specification limits on sheet steel when thickness dimensions are critical.


**SUMMARY**

Many Industrial Engineers on production or staff jobs in industry look at newer Operations Research techniques as laboratory type tools useful in the main to research people. There are many types of production problems which lend themselves to analysis by techniques of the type outlined. In the manufacturing environment, time is of utmost importance and any technique must be practical in the sense of furnishing rapid, usable results. In the case cited, simulation in no way furnished a yes or no answer to the manufacturing problem. When used as an additional tool along with the other tools of the engineer, it helped lead the study to a logical conclusion.


**REFERENCES**


(1) Churchman, C. W., Ackoff, R. L., and Arnoff, E. L., *Introduction to Operations Research*, John Wiley and Sons, New York, 1957.

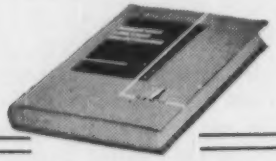
(2) Kahn, H., "Applications of Monte Carlo," Project RAND, RM-1237-AEC, Santa Monica, California, April 19, 1954.

(3) King, Gilbert W., "The Monte Carlo Method as a Natural Mode of Expression in Operations Research," *Journal of the Operations Research Society of America*, I, No. 2, 46-51 (Feb. 1955).

(4) Rich, R. P., "Simulation as an Aid to Model Building," *Journal of the Operations Research Society of America*, III, No. 1, 15-19 (Feb. 1955).

(5) The Rand Corporation, *A Million Random Digits*, The Free Press, Glencoe, 1955.





# Save money, increase production efficiency

***with these tested time-allowance methods***

HERE are the principles of work measurement and motion identification essential to a system of predetermined motion times aimed at universal application.

The book brings you exact procedures and examples showing how time data are used to set standards either through direct study or through the use of elemental standard time data.

All time data are related to a unit of motion—called Basic Motion—which has clear-cut end points that may be applied to all body members.

**BASIC MOTION TIMESTUDY.** By **Gerald B. Bailey** and **Ralph Presgrave**, of J. D. Woods & Gordon, Ltd. 189 pages, 6 x 9, 56 illustrations, $5.00

**Order from:**
**JOURNAL OF INDUSTRIAL ENGINEERING**
**A. French Building, 225 North Ave., N.W.**
**Atlanta 13, Georgia**

## BANNERS FOR SENIOR AND STUDENT CHAPTERS

**Cost $75.00**

4 x 8 ft., blue and gold felt, with a blue, gold and white embroidered AIIE insignia in the center

Available from: AIIE Headquarters
145 North High Street
Columbus 15, Ohio

(Allow about six weeks for manufacture and delivery)

## FUNCTIONS AND BASES OF TIME STANDARDS

*By H. O. Davidson*

Revised Edition 1958

(This is an expanded and revised edition by demand that this book be made available again after the first edition was exhausted.)

$4.50 per copy to members

$6.00 per copy to non-members

*Order from:*

American Institute of Industrial Engineers, Inc.

145 North High Street, Columbus 15, Ohio

# Inventorying for Unknown Demand

by WILLIAM T. MORRIS*

*Associate Professor, Department of Industrial Engineering, The Ohio State University*

A PARTICULARLY persistent and troublesome event which attends the efforts of the engineer to approach managerial decisions analytically, is the realization that most techniques of analysis require more information than is available. The bane of every analyst is the tactless associate who suddenly exclaims, "The model is just fine, but we'll never be able to get all the data it requires." The disheartening "never" may mean that the data will not be available in time to be of any use to management, or it may mean that the model is one of those which requires data which will quite literally never be measurable. At this point the analyst has the choice of either writing a deliberately naive report about the model and resorting to "experience" and judgment" for the actual decision, or attempting to find a model which offers some assistance to management but is compatible with the data actually available. This paper attempts to show how the latter process was carried out in connection with the familiar problem of fixing inventory levels in the face of varying demands. The value of models, even unquantifiable ones, as educational devices for imparting insight and understanding to decision makers cannot be denied. If, however, quantification is desirable or interesting to the analyst, then the "weakening" of models to the point where they contain only measurable variables may be a useful process.

## OPTIMUM INVENTORY LEVEL

One instance of this process arose in the situation described below in which it was necessary to determine inventory levels in the face of unknown demand. The well known theory which deals with the fixing of stock levels in the face of uncertain demand requires the following information (3).

$C_1$ = the unit cost of being overstocked
$C_2$ = the unit cost of being understocked
$D$ = number of units demanded during the period for which the stock level is being established
$f(D)$ = density function of $D$
$S$ = the stock level

The theory suggests that the optimum stock level, $S'$, must satisfy the following equation

$$F(S') = \frac{C_2}{C_1 + C_2}$$

where $F(S')$ is the probability that demand will $S'$ or less. This stock level will minimize the expected cost of inventorying.

With the variables given the expected total cost associated with any stock level may be expressed as:

$$TC(S) = C_1 \int_{D=0}^{S} (S - D) f(D) dD + C_2 \int_{D=S}^{\infty} (D - S) f(D) dD$$

By taking the first derivative of the expected total cost with respect to stock level, it is easily shown that the optimal stock level, $S'$, satisfies the following equation:

$$\int_{D=0}^{S'} f(D) dD = F(S') = \frac{C_2}{C_1 + C_2}$$

In the case where the commodity is measured in discrete units, the result turns out to be

$$F(S' - 1) \leq \frac{C_2}{C_1 + C_2} \leq F(S')$$

To illustrate, suppose a commodity is stocked on a weekly basis, meaning that the stock level must be fixed at the beginning of the week and cannot be later modified. If more material is stocked than is required, a cost of \$1.00 per unit is incurred ($C_1$). If more is demanded than has been stocked, a penalty of \$9.00 per unit is associated with being unable to meet the demand ($C_2$). The analysis requires an estimate of the density function of demand, which might be Poisson with a mean of 20 units per week. It must be that

$$F(S') \geq \frac{\$9.00}{\$1.00 + \$9.00} = .90$$

and

$$F(S' - 1) \leq .90.$$

A table or chart of the cumulative Poisson distribution shows that the optimum stock level is 27 units. The application of this model may present various data collection difficulties, but the one of interest here concerns the density function of demand, $f(D)$. Clearly in many situations it will be possible through the study of past de-

* The author is indebted to the referee for valuable suggestions made during the review of this paper.

mand, trends and possible future contingencies, to form an estimate of the demand probability distribution. However, there are situations as well, where this may not be possible. For example, the commodity stocked may be a new one for which no demand data is available. It may be that (as so often happens) no records are available on past demand for a commodity, and thus no basis for prediction exists. Again, it may be that some of the factors which determine demand are believed to have altered to such an extent that predictions are not possible. The best move in such situations is, of course, to set in motion the process of collecting data upon which predictions may be based in the future. This, however, does not solve the problem of fixing a stock level for the present.

**DECISION THEORY**

If the analyst is interested only in solutions which minimize expectation, then without the density function of demand, nothing can be done. If, however, he is willing to explore other principles of choice, decision theory has several suggestions to offer (2). If the demand distribution is unknown then the decision falls into the class of "decisions under uncertainty" for which a number of principles of choice have been suggested. Four of these principles are applied to this problem below. It must be said immediately that no definitive argument can be given in favor of any one of these principles. Their use simply removes the application of judgment to the level of selecting a principle of choice. This judgment can best be made by understanding something of the properties of each principle and selecting the one which seems appropriate to the larger context in which the decision problem arises. The interesting feature of the application at hand is that all four principles which will be discussed yield the same decision as to the proper stock level.

Before taking up these principles it is necessary to be more precise about the analyst's "degree of ignorance" of the demand probability distribution. If he is literally "completely ignorant" of the demand distribution, this must mean that demand could be anywhere between minus infinity and plus infinity. Not much can be done in this case, but it is hardly a realistic situation. On the other hand the analyst may be only "slightly ignorant" of the demand distribution, in the sense that he may have a rough idea of the mean and variance of the distribution, and possibly even some notion of its form. If this is the situation, then perhaps the best thing to do is to use these rough notions in the original model, or appeal to some limit theorem such as Tchebycheff's Inequality (1). The degree of ignorance presumed here lies between these two. It will be assumed that the analyst is able to predict a finite minimum and a finite maximum for demand, and nothing more. We assume without loss of generality that the minimum demand is taken to be zero and the maximum demand is taken to be $\overline{D}$ units.

**LAPLACE PRINCIPLE**

The first principle of choice for decisions in the face of uncertainty which will be discussed is called the Laplace Principle or the Principle of Insufficient Reason. This rule suggests that when a decision depends upon a set of future events, the probabilities of which are unknown, one should assume the events are equally likely. Another version states that in the absence of reasons for other assumptions, equal probabilities may be assumed. In application to the inventory problem this would lead to the assumption that the demand distribution is a Uniform Distribution over the range 0 to $\overline{D}$. Having made this assumption, one then returns to the original model and computes the inventory level which will minimize total expected costs. It is easily shown that

$$\int_{D=0}^{S'} f(D)dD = F(S') = \frac{S'}{\overline{D}} = \frac{C_2}{C_1 + C_2}$$

which yields

$$S' = \frac{C_2\overline{D}}{C_1 + C_2}$$

Thus the result given by the Laplace Principle depends directly on the limits which are assumed for demand. Unfortunately very little can be said in favor of this principle. It is essentially arbitrary and without a priori justification, unless of course, one really suspects that demand is Uniformly distributed.

Returning to the numerical example given above, suppose it is no longer possible to assume that the demand distribution is Poisson. Suppose, in fact, that the strongest statement that one is willing to make is that the week's demand will be more than ten units but less than 40 units. Clearly this statement will lead to stocking at least ten units, but how much more? Given these first ten units, the maximum additional demand is 30 units and the minimum additional demand is 0 units. Using the same costs as before, the optimal stock level suggested by the Laplace Principle will be

$$S' = 10 + \frac{(\$9.00)(\overline{D} = 30)}{\$1.00 + \$9.00} = 37 \text{ units}$$

**MINIMAX PRINCIPLE**

A more widely used principle is the famous Minimax Principle, which suggests that in decisions in the face of uncertainty one should choose so as to minimize the maximum possible loss. In the inventory situation this would mean selecting the inventory level which will make the maximum possible cost as small as possible. Clearly for any inventory level $S$, the maximum loss will be sustained either when demand takes the value 0 or the value $\overline{D}$. Figure 1 shows that maximum cost as a function of $S$. The value of $S$, say $S'$, which will minimize the maximum cost satisfies the following equation.

$$C_1(S' - 0) = C_2(\overline{D} - S')$$

It follows that

$$S' = \frac{C_2\overline{D}}{C_1 + C_2}$$

which is the same result obtained when the Laplace Principle was applied.

The Minimax Principle is a conservative one. It focuses attention on the worst thing that can happen and leads to action which will mitigate this worst thing. It has application in situations where losses are difficult to tolerate, where adventurous possibilities for profit are scorned, and where caution and conservatism prevail.

The antithesis of the Minimax Principle might be called a Minimin Principle. It would suggest choosing so as to make the minimum cost as small as possible. This does not result in the selection of any particular stock level, since the best thing that can happen is to guess exactly what demand will be. If stocks thus match demand exactly there will be no cost due to either understocking or overstocking. However, many decision makers would like to operate somewhere between extreme pessimism or conservatism on the one hand, and extreme optimism or adventurousness on the other. To meet this need for moderation a principle has been formulated which is called the Hurwicz Principle.

**HURWICZ PRINCIPLE**

The Hurwicz Principle requires the selection of an index of the decision maker's pessimism or optimism of outlook. Let this index be symbolized by $\alpha$, and let it be defined over the range

$$0 \leq \alpha \leq 1$$

If $\alpha$ is close to 1, then the decision maker is optimistic, if it is close to 0, then he is pessimistic. The process of choosing in actuality may be a difficult problem, but assume the decision maker is able to select an appropriate value. The Hurwicz Principle then suggests that for each stock level one compute the maximum possible total cost, $TC(S)_{max}$, and the minimum possible total cost, $TC(S)_{min}$. Then the stock level should be selected which will maximize the function

$$\alpha TC(S)_{min} + (1 - \alpha)TC(S)_{max}$$

Returning to Figure 1, it will be seen that for

$$S \leq \frac{C_2\overline{D}}{C_1 + C_2}; \quad TC(S)_{max} = C_2(\overline{D} - S)$$
$$TC(S)_{min} = 0$$

The Hurwicz criterion takes the form

$$\alpha(0) + (1 - \alpha)C_2(\overline{D} - S)$$

This function will be maximized, for any $\alpha$, if $S$ is made as close to $D$ as possible. Here this means

$$S' = \frac{C_2\overline{D}}{C_1 + C_2}$$

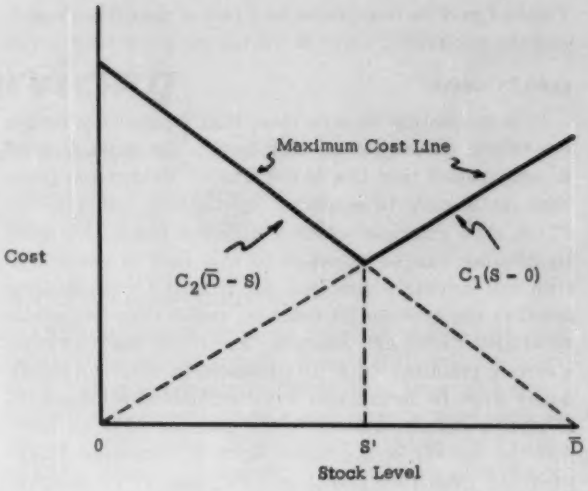



FIG. 1

Now for $S \geq \frac{C_2\overline{D}}{C_1 + C_2}$; $TC(S)_{max} = C_1S$

$TC(S)_{min} = 0$

and the criterion function becomes

$$\alpha(0) + (1 - \alpha)C_1S$$

Maximization is now achieved by making $S$ as small as possible, thus

$$S' = \frac{C_2\overline{D}}{C_1 + C_2}$$

Finally over the entire range of $S$, for any $\alpha$ whatsoever, the Hurwicz Principle suggests that the stock level should be

$$S' = \frac{C_2\overline{D}}{C_1 + C_2}$$

which is again the very same result obtained before.

**SAVAGE OR REGRET PRINCIPLE**

Because of certain intuitive difficulties associated with the Minimax Principle, still another rule for choice arose called the Savage or Regret Principle. It defines, for any stock level and any demand, the difference in cost between the minimum cost achievable had demand been known in advance and the cost resulting from the stock level in question, as the decision maker's regret. Thus for any demand, if $S$ stock level had been chosen equal to demand, cost would be 0, and the regret associated with any other $S$ would be $C_1(S - D)$ or $C_2(D - S)$, depending on whether $S$ was greater or less than $D$. Having computed the regret for each $S$ and $D$ combination, the principle suggests that one select the stock level which will minimize the maximum regret. Since, for any $D$, the minimum possible cost is 0, the maximum regret turns out to be equal to the maximum cost for any $S$. Thus

Figure 1 may be interpreted as a plot of maximum regret, and the minimizing value of $S$ is the one previously found.

## CONCLUSIONS

It is interesting to note then, that whatever principle one selects the suggested stock level is the same. It must be emphasized that this is not true of all decision problems. It is easy to construct or discover examples for which each principle yields a different result. No great significance can be attached to this fact in connection with the inventory problem, for it is the mathematical result of the problem formulation, rather than any subtle generality which has emerged. The result has, however, a certain practical value for situations in which inventory policy must be formulated without demand information. It gives a definite answer to the question of stock level, and the answer is the same when the question is approached from four points of view. Best of all perhaps, the answer has certain demonstrable properties, such as minimizing the maximum cost, which are directly appealing to the decision maker.

A more general result of this analysis is to suggest that perhaps all is not lost if we cannot attain the levels of information completeness now customarily sought in the study of management decision problems. The two outstanding facts of life in this business seem to be; A. almost never will we have the time, money, and ability to obtain all the information we would like to have for a decision; B. the more information that it missing, the less the opportunity to produce logical and valid recommendations for management. Fact of life number B notwithstanding, the principles suggested above, have two important attributes. They make the decision process explicit so that it can be studied, reviewed, criticized, and improved. They also promote consistency through the use of such information as is available and the clarification of the guesswork that must be thrown in. Viewed in this light, the field of decision theory is not "far out," but extremely "practical."

## REFERENCES


(1) Feller, William, *An Introduction to Probability Theory and Its Applications*, John Wiley and Sons, New York, 1957.

(2) Luce, R. Duncan, and Raiffa, Howard, *Games and Decisions*, John Wiley and Sons, New York, 1957.

(3) Naddor, Eliezer, "Some Models of Inventory and An Application," *Management Science*, July 1956.

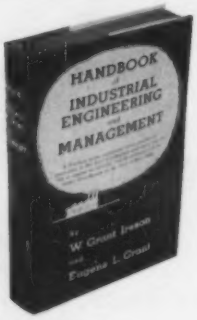


HANDBOOK

**Industrial Engineering**

AND

**Management**




***Edited by W. G. Ireson and E. L. Grant***

A complete reference book for the industrial engineer, manager, businessman and student on the fields of activity commonly considered to be part of industrial engineering. There are 17 sections in all. Each section is complete in itself and is written by an outstanding authority in the field.

Cross-referenced and fully illustrated, there are sections on: structure of business organization, managerial economics, engineering economy, manpower management, motion and time study, factory systems and procedures, industrial climatology, tool engineering, industrial safety, inspection and quality control, and many others.

**1208 pages** **6" x 9", double col.** ***$16.00***

*Order from:*

**Journal of Industrial Engineering**
**225 North Ave., N. W.**
**Atlanta 13, Georgia**

*Bringing you*

**needed design facts and technical data on today's engineering materials**

In this handbook you will find almost 2,000 pages of answers to both routine and unusual problems that crop up whenever engineering materials are being selected. Technical tables, design information, structural characteristics, and tabular data—a wealth of useful and specific facts —are made quickly available.

*Just Out!*

**ENGINEERING MATERIALS HANDBOOK**

Edited by CHARLES L. MANTELL, Consulting Engineer
Newark College of Engineering. *1906 pp., 648 illus., $21.50*

Each of the 43 sections was prepared by one or more specialists. A staff of 150 of these experts cover metals, organic materials, and inorganic materials. Emphasis is placed on the fabricated forms of materials, their physical and mechanical properties, their adaptations, advantages, limitations, competition with each other, protection against deterioration, and increase in their stability to withstand use and abuse.

In line with today's needs, the Handbook covers such items as the uncommon metals which are rapidly reaching commercial importance and production, and the materials of construction of apparatus for control and utilization of atomic forces and fission products.

**Order from**
**Journal of Industrial Engineering**
**A. French Bldg., 225 North Ave., N.W.**
**Atlanta 13, Georgia**

# Cyclic Servicing

*by* **THOMAS F. O'CONNOR**

*Management Consultant, Oakland, California; Associated with the Institute of Textile Technology, Charlottesville, Virginia*

ARGUMENTS in favor of cyclic servicing, as opposed to random servicing, in connection with machines which stop in a random manner, are not conclusive because hitherto no general formula has been available for calculating the results which may be expected from cyclic servicing.

The aim of the following paper is to help in evaluating the cyclic procedure by presenting a formula for calculating the standard efficiency of a group of semi-automatic machines assigned to one operator who will service them on a cyclic pattern. Proof of the formula is given, followed by a demonstration of its use.

## THE PROBLEM

What average productivity is it reasonable to expect from a group of semi-automatic machines serviced by one operator? What are the factors which influence the productivity, and what is the effect of each? These are questions which require answers before sensible assignments can be made, and fair standards of productivity set.

One factor is immediately recognized as major. It is the routine by which the machines are serviced. There are two principal routines, which will be more particularly described later, known as random servicing and cyclic servicing. Other factors are: work content, machine speed, operator speed, operator relaxation, frequency of machine stops. When these are held constant, the servicing routine decides how much production will actually be achieved. Sometimes a line is drawn arbitrarily. In connection with a certain type of loom, for instance, the statement is made that the assignment 40 per operator is critical—below, use random servicing; above, use cyclic servicing. It is true that inspection is more assured when the operator is made to patrol the looms as in cyclic servicing. With random servicing the operator may slight the inspecting of his machines. But what about productivity—is it improved or otherwise? In fact, what productivity is to be expected?

An estimate of productivity is important to management in several of its functions: production planning (sometimes in conjunction with linear programming), wage payment, pricing of the product, budgeting, and so forth. Much has been published on estimating productivity when the servicing is random.* Here an attempt is made to do something for the case of cyclic servicing.

## MACHINE CHARACTERISTICS

There are many types of machine which, with only intermittent attention from an operator, will automatically perform productive work. One type will weave fabric; another will draw metal wire; a third will lay up an electric cable. Some of these are so big and the operator's tasks so complex that a number of operators are required for one machine. We are not concerned with these. On the other hand there are many cases where the operator's work takes much less time than the unattended machine run, and in these cases a single operator will handle a number of machines. It is this order of machine that is the subject of this paper.

Every machine has stops for loading and unloading which could be scheduled in advance if there were no disturbing factors. Many machines do in fact run to schedule. A greater number, however, have random stops in addition to the regular (or quasi-regular as they now become) and the program of the machine becomes disordered. For the purpose of the discussion, the type of machine which has only regular stops will be termed "ideal automatic," an dthe machine subject to random stops as well as the regular will be termed "semi-automatic."

The term machine will indicate any mechanically or electrically driven producing unit which can be run or stopped independently of its neighbors. This obviously describes a loom or a wire drawing machine, but what is not so obvious, it also describes a single spindle of a winding frame when each spindle has an independent drive.

## SERVICING ROUTINE

When the stops occur only in a regular sequence, as with the ideal automatic, naturally the operator will attend to the machines in a regular sequence. He will proceed from No. 1 as soon as he has set it running to No. 2 which has just stopped. Then he will go to No. 3 and so

---

* For random servicing the bibliography on *Queueing Theory*, by Vera Riley, published by the Operations Research Office, The Johns Hopkins University, Chevy Chase, Maryland, April 1957, is the most complete so far. In particular, reference may be made to the published work of the author: *Probability and Productivity*, Emmott and Company, Manchester, England 1952. Other articles may be found in *Textile World, Textile Industries, Textile Bulletin*, etc.

on to the $n$th, finally returning to No. 1 to start the cycle all over. This is cyclic servicing. He could pass from No. 1 to No. 3 and wait for No. 3 to stop, ignoring No. 2 which has stopped already, but such a procedure would not make sense. In fact, no procedure other than cyclic servicing would make sense in connection with ideal automatic machines.

When the stops occur at random, as with the semi-automatic, the natural procedure for the operator is to attend always to the stopped machine nearest to hand. This is random servicing, and it is very commonly used. But in this case it is not true to say that no other procedure would make sense. Cyclic servicing could be adopted, and in fact is advocated by many people. Figures to evaluate the two procedures are needed. Information on random servicing is already available, but for cyclic servicing on semi-automatic machines the published information is meager.

## LAYOUT OF MACHINES

It is assumed the machines are all similar and on similar work. The layout of the machines affects the answer and for present purposes there are only two kinds of layout—one in which the end of a single walk along the complete array of machines would find the operator back at the starting point; and one in which the operator has to walk the full length of the line to get back to the starting point. The first will be called closed circuit, and the second will be open circuit. The work to follow will relate to the open circuit layout, but a simple change, which will be indicated, will take care of the other type.

In genuine cyclic servicing, the operator moves in one direction along the line of machines, servicing each stoppage as he reaches it, but rigorously avoiding a backward move even if a machine stops within a split second of his passing it. On reaching the end of the line he may take some relaxation. When ready for work, he will start again with No. 1. In the case of open circuit he will of course have to walk some distance first, but if the arrangement is closed circuit, there will be only the usual movement across the gap between adjacent machines.

## THE OPERATOR

Assuming the operator's pace does not vary whether walking or working, the time taken over one patrol will depend on the number of stoppages encountered, assuming also that the average repair times are also roughly equal, while the number of stoppages encountered will naturally depend to some extent on the duration of the patrol. On account of this interdependence of the patrol time and the number of stops per patrol, it is not easy at first glance to see how to figure the average condition. An additional complication is the operator's relaxation.

It would not be so if the operator took all his relaxation only after shutting down all his machines once or twice per shift. In that case the shutdown would merely abridge the productive time available, and the calculation would be simple—an advantage, although the practice itself might be open to objection from the management point of view. But if the operator absents himself for varying periods at irregular intervals, leaving some machines running and some stopped, obviously this would affect the patrol time in a manner difficult to predict—perhaps "impossible" would be a better word.

At this juncture it is important for the Industrial Engineer to remind himself that he is not concerned with predicting the results of individual performances or individual performers. He is concerned with setting up realistic standards or norms of performance to cover actual conditions over a relatively short period, and, when necessary, revising them so as to cover new conditions. In the present case it seems reasonable to assume that the needs of the average operator will be met if he takes a breathing spell at the end of each patrol without stopping the machines, and we will use this assumption in building up the standard. One other factor remains—operator work pace. We do not propose to enter into the contentious arena of rating and leveling practices, but merely point out that the method we are about to describe will work with whatever times are put into it. The results will be as valid as the times, no more and no less.

## THE FORMULA

If the machines ran non-stop for 60 minutes every hour, each would achieve 1 *mrh* (*mrh* is an abbreviation for machine running hour) per hour, which is another way of saying the efficiency is 1.0 (or 100%). But the machines do not do this, they have stops causing losses as regards productivity, and averaged out over all the $n$ machines of one assignment the losses per machine per hour amount to

$$\frac{s}{2n}$$

So the operating efficiency will be given by

$$E = 1 - \frac{s}{2n} \qquad \text{Eq. 1.}$$

and this is the required formula.

In this formula, $s$ is the average number of stopped machines the operator encounters per patrol. The expression for evaluating $s$ is:

$$s = \frac{b + \sqrt{b^2 + 4ac}}{2a} . \qquad \text{Eq. 2.}$$

We will explain the factors $a$, $b$ and $c$ in turn.

*Factor a:* $a = qt$

where $q$ is the average number of stops on average per *mrh*, and $t$ is the average operator work time per stop (in minutes). Both $q$ and $t$ are obtained from the time studies.

*Factor b:* $b = qn\ (2t - w) - 120k$ (closed circuit)
$b = 2\ qn\ (t - w) - 120k$ (open circuit).

In these two expressions, $w$ represents the average time required to walk from one machine to the adjacent machine (minutes). $k$ represents what is left of the working hour when the relaxation allowance has been subtracted. $k$ therefore is a quantity less than 1.

*Factor c:* $c = 4qn^2w$ (open circuit).
$c = 2qn^2w$ (closed circuit).

Walk time $w$ is computed as $L$ multiplied by a constant, where $L$ is the distance in feet from center to center of adjacent machines. The value of the constant is the time in minutes required to walk a distance of one foot, and different people will have different ideas as to what is adequate. We will use the value .005 min. per foot corresponding to a speed a little less than 3 miles per hour. This is arbitrary, but will serve for illustrating the calculations. It may be argued that the movement will be much slower than walking pace since the operator will be inspecting as he goes along. The reader is free to insert his own choice instead of the figure we have given.

**USING THE FORMULA TO FIND THE STANDARD EFFICIENCY**

Data

| | |
|---|---|
| One operator has 20 machines. | $n = 20$ |
| Each stops on average 12 times per mrh. | $q = 12$ |
| Average repair time per stop is .2 min. | $t = .2$ |
| The operator is allowed 12% of total time for rests. | $k = .88$ |
| The distance from center to center of adjacent machines. | $L = 20$ feet |
| The machines are arrayed in one straight line. | Open circuit. |
| Required—the standard machine efficiency. | |

In solving, we first evaluate the factors $a$, $b$ and $c$, and so to proceed to find $s$. Then we use Eq. 1. to find $E$.

*Factor a:* $a = qt = 2.4$

*Factor b:* $b = 2qn(t - w) - 120k$, *where* $w = .005L = .01$ whence $b = (-14.4)$, and $b^2 = 207.36$

*Factor c:* $c = 4qn^2w = 192$.

Omitting the figuring, $s$ is found to be 6.42, and it follows that $E = .84$.

Answer: For the conditions stated, the standard efficiency would be set at 84%

The answer implies that we expect and are prepared to tolerate losses amounting to 16%. Two further questions naturally jump to mind at this point—how do these losses compare with those involved in random servicing, and how do they compare with those on ideal automatics? The latter question may be paraphrased as follows: If the stops could be made to occur to schedule so that there were no losses due to waiting, what would the losses total? It is not difficult to answer this. The stop time would be 2.4 minutes for a machine run of 60 minutes, giving a cycle time of 62.4 minutes. The standard efficiency under these conditions would be .962 ($=60 \div 62.4$). The loss is .038 or 3.8% instead of 16%, so we see that approximately 12% of production time is lost through waiting on the part of the machines after stopping which would not occur if the machines were ideal automatics. The first part of the question is beyond the scope of this paper, but the answer may be obtained by the use of information which I have published elsewhere. (See footnote.)

With 6.42 stops to be repaired on the average patrol, the average time of a patrol, including allowances, will be 1.91 minutes. Of this, about .226 minute represents time the standard operator would spend resting. (The necessary equations for deriving this information are contained in the section headed "Proof.")

**SPEED**

*Operator Speed.* What would happen if the operator speeded up by 25%, or (what amounts to the same thing) if his tasks were cut by 20% and he worked at his old pace? Going back to the data we see that $t$ would become .16 min. (in place of .20) but that otherwise there would be no change. Making the substitution and following through factor $a$ becomes 1.92, factor $b$ becomes $-33.6$, and $b^2 = 1130$. Factor $c$ becomes 192 same as before), and $4ac$ becomes 1475. $s$ becomes 4.53, and $E$ becomes .887.

This indicates the operator is beating his quota, but not by 25%, of course; in fact only by 6%. He is doing 47 patrols per hour, averaging 1.28 minutes each (including .153 minute rest each time) compared with 31.4 patrols averaging 1.91 minutes each (with .226 minute rest included) when he operated at the original pace. One point of interest is that he is always busy (since the stipulated rest is part of his business) regardless of the number of patrols per hour, and in fact regardless too of the number of machines assigned. This is a feature of cyclic servicing. When the servicing is at random, he may have idle spells unless it is laid down that he must patrol on occasions when all machines are running.

*Machine speed.* Now let the operator work at his original pace so that $t$ is .2 min. again, but let us speed up the machine by 25%. This time it is the factor $q$ that changes, and in fact it becomes 25% bigger since the event content of each *mrh* (the unloadings, loadings and the breakages) must keep pace with the change of speed. This is not strictly true. The breakage rate might show a tendency to increase out of proportion to the increase in machine speed, but since to investigate this would widen the scope of this paper beyond its allotted limits, we assume we are still operating in the band of machine speeds where the breakage rate is proportional to the speed, just like the other events in the cycle.

Making the substitution and following through, $q = 15$, factor $a$ becomes 3.0, factor $b$ becomes 8.4, with $b^2 = 70.6$, factor $c$ becomes 240, and $4ac$ is 2880. Then $s$ is 10.43 and $E$ is .74. The average time of one patrol is 2.82 min. of which .34 min. is the operator's rest period. There will be 21.3 patrols per hour on average. The assignment

of 20 machines under these conditions would probably be considered uneconomical.

Although the speed has increased by 25%, the efficiency has fallen from 84% to 74%. The operator's $a$ factor ($= nE$) has dropped from 16.8 to 14.8 *mrh* per hour. You ask—isn't there a mistake? Surely he will produce more, not less, at the higher speed? The answer is "yes, he will produce more, but no, there is no mistake." The paradox is resolved when we remember that the *mrh* in the first case is a different unit of production from the *mrh* in the second case. In the second case, 1 *mrh* is equal to 1.25 of the original *mrh*, so $14.4 \times 1.25 = 18.0$ *mrh* in the original units.

## USING THE FORMULA TO FIND THE BEST ASSIGNMENT

It is fairly clear that the smaller the operator's assignment, the greater the fraction of his hour that he spends in walking. The more machines he is given, the more actual work he will have to perform. What is the best assignment? To answer this we have to know by what criterion one assignment is to be judged better than another. Suppose the criterion is to be the cost of producing one *mrh*, then the assignment showing the lowest cost per *mrh* would be the best.

Let us take the data previously given and add to it the fact that the overhead cost per hour of machine use amounts to one tenth of an operator's hourly pay. Then the cost to the firm of 20 machines for one hour would be 2.0 hours pay, to which we should add the operator's own pay, making a total of 3.0 hours pay per hour.

In the hour, the standard operator would produce on average 16.8 *mrh* (from $nE = 20 \times (.84)$). The cost per *mrh* would be .1787 hour pay (equals $3.0 \div 16.8$). (Note, symbol $A$ is used for the number of *mrh* per hour obtained from $n$ machines.)

By the repeated use of the formula, similar information for other possible assignments may be found, and the results lined up for inspection. Time may be saved by setting out the calculations as shown in Table 1. These indicate that the optimum assignment for the given conditions would be about 18 machines per operator.

TABLE 1

*Calculation Sheet for Optimum Assignment Cyclic Servicing—Open Circuit*

$$s = \frac{b + \sqrt{b^2 + 4ac}}{2a} \cdot \quad \text{Let } b^2 + 4ac = d \text{ and } b + \sqrt{d} = f \quad \text{Then } s = \frac{f}{2a}$$

| *Time Study* | *Factor a* | *Factor b* | *Factor c* |
|---|---|---|---|
| $t = .2$<br>$q = 12$<br>$w = .01$<br>$k = .88$ | $a = qt$<br>$= 2.4$ | Let $l = 2\ q(t-w) = 4.56$<br>and $m = 120\ k = 105.6$<br>Then $b = ln - m$<br>$= 4.56n - 105.6$ | $4\ qw = .48$<br>$c = 4\ qwn^2$<br>$= .48n^2$ |

| Line | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 1 | Trial $n$ | 12 | 14 | 16 | 18 | 20 | 22 | 24 |
| 2 | $ln$ | 54.72 | 63.84 | 72.96 | 82.08 | 91.20 | 100.32 | 109.44 |
| 3 | $b$ | −50.88 | −41.76 | −32.64 | −23.52 | −14.40 | −5.28 | +3.84 |
| 4 | $b^2$ | 2,585 | 1,745 | 1,068 | 552 | 207.36 | 27.84 | 14.75 |
| 5 | $n^2$ | 144 | 196 | 256 | 324 | 400 | 484 | 576 |
| 6 | $c$ | 69.1 | 94.1 | 122.8 | 155.8 | 192 | 232 | 276 |
| 7 | $4ac$ | 663.6 | 903.4 | 1,178.9 | 1,492.8 | 1,843 | 2,227 | 2,650 |
| 8 | $d$ | 3,248.6 | 2,648.4 | 2,247 | 2,045 | 2,051 | 2,255 | 2,664 |
| 9 | $\sqrt{d}$ | 57 | 50.4 | 47.35 | 45.1 | 45.2 | 47.5 | 51.6 |
| 10 | $f$ | 6.12 | 8.64 | 14.71 | 21.58 | 30.8 | 42.22 | 55.44 |
| 11 | $s$ | 1.275 | 1.80 | 3.33 | 4.49 | 6.42 | 8.80 | 11.53 |
| 12 | $s/2\ n$ | .0531 | .0642 | .104 | .1247 | .1602 | .2000 | .2395 |
| 13 | $E$ | .947 | .936 | .896 | .875 | .840 | .800 | .760 |
| 14 | $A\ [= nE]$ | 11.36 | 13.10 | 14.32 | 15.75 | 16.79 | 17.60 | 18.25 |
| 15 | Hourly cost | 2.2 | 2.4 | 2.6 | 2.8 | 3.0 | 3.2 | 3.4 |
| 16 | Unit cost | .194 | .183 | .182 | .178 | .179 | .182 | .186 |

Line 15 = 1 + $nu$ where $u$ is overhead per m/c hour.
Line 16 = line 15 ÷ line 14. [Line 14 gives the no. of mrh per hour.]

## PROOF OF THE FORMULA

Under the conditions of cyclic servicing as defined, it is axiomatic that once a machine stops, it will remain at rest on average half of the average duration of one patrol. Using this as a starting point, the machine efficiency is found as follows:

1. Average patrol time with assignment $n$ machines, say $y$ min.
2. Total machine run time ideally possible per patrol = $ny$ mc. min.
3. Number of stops encountered per patrol on average, say $s$.
4. Lost time per patrol on average is therefore $sy/2$ mc. min.
5. Average mc. run time actually achieved per patrol = $(ny - sy/2)$ mc. min.
6. Mc. Efficiency, $E$, (line 5 + line 2) $1 - s/2n$.

   Machine efficiency is another name for the number of $mrh$ per mc. hour—always less than 1, of course. Line 6 states the required expression for machine efficiency for a given assignment for any operator, in terms of the number of stops per patrol. It is now necessary to find some way of evaluating the term $s$, and this is not obvious since $y$ also is unknown. However $y$ and $s$ are mutually dependent, and it is found that $y$ can be expressed in two forms both containing $s$.
7. Number of patrols per clock hour on average = $60/y$.
8. Total stops per hour on $n$ machines (average) = $60\ s/y$.
9. Average number of stops per hour on one machine = $60\ s/ny$.
10. Average number of stops per $mrh$, symbol $q = 60\ s/Eny$.
11. Using line 6 to eliminate $E$, $q = \dfrac{120\ s}{y(2n - s)}$
12. From line 11 by rearrangement, $y = \dfrac{120\ s}{q(2n - s)}$ and this is the first expression for $y$.
13. Average operator work time per stop, say $t$ min.
14. Time to walk between adjacent machines, say $w$ min.
15. Net patrol time, walk only, open circuit = $2\ nw$ min.
16. Net patrol time, work only = $st$ min.
17. Net patrol time, walk plus work = $(2nw + st)$ min.
18. Patrol time corrected for relaxation, $y = \dfrac{2nw + st}{k}$.

    This is the second expression for $y$. Equating $y$ as expressed in line 12 and line 18.

19. $\dfrac{120\ s}{q(2n - s)} = \dfrac{2nw + st}{k}$

20. It follows that $qts^2 - [2qn(t - w) - 120k]s - 4qn^2w = 0$.
21. For convenience rewrite line 20 $as^2 - bs - c = 0$.
22. Then $s = \dfrac{b + \sqrt{b^2 + 4ac}}{2a}$

    where $a = qt$, $b = 2qn(t - w) - 120k$ and $c = 4qn^2w$. Note that $k$ is the fraction of the hour remaining after allowances have been deducted. For 10% allowances, $k = .9$, for 15%, $k = .85$ and so on.

If the arrangement of the machines is closed circuit, line 15 becomes $nw$ (instead of $2nw$) and following through we find that the expressions for $s$ and $a$ are unaltered, but we have

$$b = qn(2t - w) - 120k \text{ and } c = 2qn^2w.$$

## CONCLUSION

It is believed that the foregoing relationships will be useful to mill managers and others who have the task of evaluating alternative proposals for machine assignments with cyclic servicing. The calculations at first may appear complicated, but it is not difficult to construct a work sheet such as Table 1 which renders the task a mechanical operation.


- HOW FOREMEN CAN CONTROL COSTS
- TIMESTUDY FUNDAMENTALS FOR FOREMEN
- TIMESTUDY FOR COST CONTROL
- HOW TO CONTROL PRODUCTION COSTS
- HOW TO CHART TIMESTUDY DATA

**Uncover HIDDEN PROFITS in your plant or shop with the—**

**5-volume McGraw-Hill**

**PRACTICAL COST CONTROL LIBRARY**

**By PHIL CARROLL, *1372 pages, 460 illustrations*, only $19.50**

An expert on the subject, Phil Carroll, shows you exactly how to take on cost control problems—*and solve them*—at all levels in the plant or shop. Foremen, supervisors, engineers, timestudy men—all can use these specific facts, data, and methods to get on top of cost problems in quick order.

Starting right at the front-line supervisory level, this Library points out the foreman's responsibilities for costs—gives scores of helpful suggestions on such typical foreman cost problems as changing setups, training new men, handling rush orders, eliminating waiting time, scrap, and so on.

**Timestudy techniques and applications**

From the ABC's of timestudy, this Library leads you step by step through the standard-setting processes. Complete, practical explanations cover the entire timestudy procedure—how and where to start, building standard data, applying standards, and maintaining a complete incentive installation.

A full explanation of the total-conversion-cost method of control gives you tested means of boosting profit and plugging cost leads.

**Order your Library from: JOURNAL OF INDUSTRIAL ENGINEERING**
**A. French Building, 225 North Ave., N.W., Atlanta 13, Georgia**

# Operations Research in Management Planning and Control*

*by* **W. J. McGUIRE**

*Long-Range Planning Co-Ordinator Economics and Co-Ordination Department, British American Oil Company, Limited*

OPERATIONS RESEARCH has enjoyed such a wide spectrum of application that the subject has defied precise description. Nevertheless, the following characteristics have remained since its inception:

1. Operations Research is interested in the same problems as management, whether applied to industry, government or the military. This means that it is interested in providing executives with a sound basis for evaluating the activities under their control so that the necessary decisions can be made.
2. The basic methods of Operations Research are closely akin to the methods of the physical sciences, but methods of the social sciences are also used when necessary or appropriate.
3. Of all the specialized services designed to help management, Operations Research is unique in its approach to problems. The conclusions and recommendations of an Operations Research study are related to the over-all objectives of an organization—rather than to the objectives of a particular part of the organization.

Since some of the techniques of Operations Research have been used for years by many professionals in industry it is not surprising that some of the established disciplines have claimed that the concept of Operations Research is not new.

The increased planning and control which accompanied the development of large corporations in America through mass production techniques in industry did much to integrate professional skills with operations. The engineering profession, for example, became more specialized and was divided into classes such as, Mechanical, Civil, Chemical, Electrical. Later, as these special areas of interest expanded, a new activity, Industrial Engineering, emerged to serve management better by using the traditional engineering skills in a new area of interest in the corporate structure.

However, as engineering and other professional activities became more closely associated with the corporation, many of them lost the scope which has been preserved by the legal and medical professions. While industry did create new opportunities for specialists in certain areas such as research, many were confined to the routine of day-to-day business. Professionals who felt their capabilities were being limited found that one way they could make a great contribution was by joining the ranks of management, and this is what many of them did.

### THE SCIENCE OF MANAGEMENT

Today, we hear a great deal about a new professional—the manager, and a new discipline—management science. And in this application of the scientific method to the complexities of modern industry we find a field in which the professional can satisfy the urge to extend his scope.

Operations Research by its nature is uniquely suited to study and define the problems facing management. No one has a monopoly on Operations Research and, as yet, there are very few real experts in the field. It is important for all professionals in industry to recognize the potential of Operations Research and learn its techniques and use it to aid management in resolving its problems so that better decisions can be made. This will certainly be necessary if industry is to increase production and meet the needs of our economy.

By definition, Operations Research approaches problems as they relate to the over-all objectives of the organization—not a particular part of it. This raises the question of why an Operations Research group should be organizationally in any one department. An Operations Research group should report at a level of authority that is consistent with communication downward to the persons that will implement its recommendations. Thus provided an Operations Research group is conscientious in considering the effect of its studies in the total operation, it can successfully operate either at the department or the company level.

An essential aspect of the methodology of Operations Research is the construction of a scientific model of the system under study. With the model the researcher manipulates the system and determines how it can be changed to maximize its effectiveness.

### THE ACCOUNTING MODEL

The best known and most useful descriptive model in business is the accounting system. Historically, the accounting model has done a yeoman's job. Before the Industrial Revolution took place, most businesses were

* Based upon a presentation to the Southern Ontario Chapter of AIIE, May 29, 1958.

headed by one individual who performed all management functions: selling, production, scheduling, purchasing, financing, hiring and firing, etc.

With the mechanization of production and the subsequent growth in industry, management underwent a functional division of labor; the sales manager, the manager of production, the manager of finance, the personnel manager, etc., became familiar figures in the corporation.

With the continued growth of industry, even these management jobs were sub-divided. The manager of production, for example, became a vice-president, who was served by managers of purchasing, maintenance, quality control, manufacturing and the like. In this way, various executive levels developed in which a manager in control of other managers became known as an executive. The planning and control of company operations was still largely performed by these executives. The accounting model provided a budget for these plans and financial control of the over-all results.

In the course of the evolution of industrial management, a new set of problems emerged out of the division of management labor which required the formulation of objectives for each functional department of the business. Different points of view developed within the business which frequently were in disagreement with regard to company policies.

Let us take an example of a typical problem of inventory as it might arise in business. The production department usually looks at inventory in the following way: since it is interested (among other things) in minimizing the unit cost of production, it can best accomplish its objective by producing a relatively small number of different items in few but large production runs. This reduces set-up costs, but such a policy requires a large inventory spread over relatively few products.

The marketing department, on the other hand, is interested in supplying its customers with any of their demands almost immediately; consequently, it too is interested in large inventory but of a different kind. It would like to have an inventory spread over a large number of products rather than concentrated in relatively few. Furthermore, it would like to have a production department that is not committed to a program of large production runs but one that remains flexible so that it can make special orders quickly.

The finance department is interested in maximizing the return on investment. One way of doing this is to reduce the investment required to maintain a volume of business. This usually leads to the finance department's preference for as small an inventory as possible.

Finally, the personnel department is interested in minimizing the amount of hiring and firing that goes on. This can only be done if there is excess production during slack periods which means building-up inventory. Consequently, it is interested in large inventory but again for different reasons. Several or all of these points of view may come into conflict with one another. No one of these points of view necessarily corresponds with a point of view that is best for the company as a whole. The problem of setting a policy that affects all functions of the business in the best way for the company as a whole is an executive problem.

Here the accounting model breaks down as a planning mechanism. Fundamentally, it predicts future costs from past experience and relies on planned operations closely paralleling historical operations. This sort of information puts management in the position of an individual trying to drive an automobile forward in traffic with his eyes fixed on the rear-view mirror. We obviously need a model that will more adequately represent the system.

## A CASE EXAMPLE—STAGE I

At British American Oil the existing accounting system included financial and production data. To provide additional data required for planning and control of the manufacturing operation, the manufacturing division had evolved a supplementary system of records—Manufacturing Operations Summaries. These contained production, quality and operating data. Since production data was common in both records, it was possible to collate these and produce correlated data. This could be used to both plan and evaluate the operations so that objectives could be established and the operations required to produce them could be defined and controlled.

A team of three people initially, studied this problem and defined a method. The team consisted of a Chemical Engineer with post-graduate mathematical and statistical training, a Chemist with operating, process engineering and plant administration background and an Accountant with broad accounting experience in our company.

The past records in the financial, accounting, quality and operating areas at each refinery were analyzed to find out if a realistic relationship existed between operations, quality, production and the resultant cost. To do this, we used data covering the previous two years. This gave us 24 one-month periods with which to work.

We next used Regression Analysis and Multiple Correlation by means of which equations were calculated to express the relationship between the various expense elements of each area and its total monthly cost in dollars. In short, a small mathematical model was created from which we could predict the cost when given certain activity levels and conditions.

We found these refinery cost functions effective in forecasting operating expense for any given operation within the range of the data used to calculate the formulae. This meant that alternative operations on the various units with different crude oils could be examined to determine the effect on cost.

Traditionally, planning at British American had been done by the case study method where various alternatives of operation were prepared and costed by the Comptrol-

ler's department and the most profitable operation chosen. In preparing these cases, models of the refineries' operations were used based on individual experience and judgment. It was difficult to be sure that these cases were kept comparable and impossible to optimize operations under any case considered.

We saw that if cost of crude oil (raw material), operating expenses and quality factors could be correlated, these could be optimized. The problem then was to establish mathematical models of refinery operations for use in evaluating and planning manufacturing operations. This was accomplished by a team consisting of a Chemical Engineer with statistics and Operations Research training, a Chemical Engineer with plant operating and process engineering experience, a Mathematics and Physics graduate and a Mathematics and Statistics graduate. This team worked with a rented computer facility.

An analysis of the system was carried out using regression and multiple correlation techniques that established basic relationships within the range of past experience. A mathematical representation of a refinery was made and an optimization of operations was made using linear programming. This demonstrated that the approach was feasible.

The original models were simply alternative methods of processing various crudes through a refinery as a whole. This was adequate for evaluating crude oil selection, but was not detailed enough to take advantage of all the potential flexibility in the system. Models based on the individual refinery units solved this problem. It was now possible to optimize raw material selection, process sequence, quality and product mix for minimum cost. Conversely, profit could be optimized for any given market demand.

Using linear programming we could not only optimize crude oil selection and plant operations with respect to cost, but also examine inter-plant relationships and the effect of including marketing and transportation activities, to insure that manufacturing operations were not being optimized at the expense of the other departments. A linear planning tableau of the whole system was developed. Previously established geographical areas of product demands with attendant economic transportation systems were used as possible destinations. Modification of these areas in light of other costs results from the overall optimized solution.

The evaluation of profitability of manufacturing versus purchase was made by allowing purchase of product at the refineries and fringe transportation points. The profitability of additional or changed sales of given products was examined by allowing additional manufacture of products with a given profit incentive. Capital investments were evaluated by adding them to the tableau and calculating the payout.

The computer program involved a number of interesting features. The optimization was designed to proceed step-wise so that a series of alternative plans would be calculated and a preliminary evaluation of existing conditions and policies could be made to assist management in defining a base against which other alternatives of operation would be evaluated.

**STAGE II**

This takes care of Stage I in our program. Stage II consisted in defining a series of alternatives of possible new conditions such as new facilities, qualities, price structure, markets, and so on, to define an operating strategy. The program was designed so that the output from the computer would be a series of cases which:

1. Reasonably compiled with existing reporting procedures for ease of presentation to management.
2. Made sufficient definition of operating detail that a final decision could be readily implemented with existing organization and procedures.
3. Conformed with existing accounting data for check evaluation through normal accounting channels by the comptroller and ready translation into the conventional profit picture.

British American has completed a series of these studies which began in 1957 largely in the Manufacturing activity and were extended in 1958 to include interaction with the other departments. As a result, the Manufacturing Operations Control function has been re-organized to take advantage of this method of operation. An Operations Analysis group has been established to provide the control and feed-back of data to maintain the planning on a continuing basis. An Operations Planning group using these methods has been set up to continuously plan manufacturing operations in relation to other departments of the company; and the production control group are integrating their scheduling and control procedures with the new method.

A Long-Range Planning department has been established at the corporate level to extend these methods to all departments of the company. This group has now completed studies for 1959 on a company-wide basis and is working on 1960, 1961 and 1962.

The results of these studies not only aid management in making better decisions but also in establishing departmental objectives required to implement a company-wide strategy which will improve operations and optimize profit.

To describe briefly the types of policy and strategy decisions that are examined by such a study, let us look at some of the results. In eastern Canada our operations involve expenses in the order of $120,000,000. The profitability of optimized versus conventionally planned operations will vary depending on how much planned operations differ from historical. Generally our studies indicate optimized solutions will be between two and three million dollars better under relatively stable conditions and as much as five to seven million dollars where planned conditions are radically different. This advantage can reduce quickly as experience is gained under the new conditions.

In Stage I, the following are examples of the types of decisions examined in arriving at a base case. Four crude oil sources supply our two eastern refineries, which in turn are linked to four marketing areas by pipeline, marine, rail and truck transportation facilities. The first optimized solution shows the two refineries operating to supply the market demand in their own economic freight area.

The next solution allows interaction between the refineries and the market areas to evaluate transportation economics versus raw material and process costs. Here the solution was improved by $2,300,000.

The next solution allowed purchase of products at the fringe marketing points from a transportation cost standpoint. Here purchases were accepted in the Maritimes, improving the solution by an additional $800,000. The next solution designed to evaluate the "make" or "buy" decision provided no improvement because no purchases were accepted at the refineries.

The next series of solutions evaluated a number of additional amounts of large-volume, low-margin, non-recurring business and the profitability was improved by a further $1,300,000 by including certain of these volumes.

These cases were presented to management and agreement reached on a policy for the year's operations as represented by a particular case.

In Stage II, the following are examples of the types of alternatives considered: For a number of years, the profitability of the asphalt business had been questioned, so a solution was made eliminating this product. It demonstrated that this business was contributing $4,000,000 to our profit.

Another alternative evaluated the capital expenditure for equipment to process cheaper crude oils available which were not normally acceptable from a quality standpoint. This solution indicated an $800,000 improvement or a 3 to 4 year payout at the Montreal refinery. The same equipment at our Clarkson Refinery indicated an improvement of $1,500,000, or a payout of about two years. However, installation of the equipment at both refineries simultaneously would effect an improvement of only $1,650,000. This is an interesting example where a single expenditure achieved nearly all of the potential savings which could not have been foreseen from the independent evaluations.

The Research department had been studying some Canadian crude oils versus Southern American crude from a quality standpoint for asphalt manufacture. An evaluation of this indicated a $640,000 advantage to the Canadian crude if it proved of acceptable quality.

An evaluation of the optimum product mix above the demand was made and cost differences established, costs and quantities of individual products were also established. These studies not only indicated the optimum production with existing facilities but also indicated unit limitations at this point.

The Stage II solutions were now submitted to management and a decision made on the final operating strategy and departmental objectives established for planning detailed departmental operations.

The linear programming tableau used to do the above studies involves the use of about 75 equations and 300 variables. Typical basic IBM 650 time requirements are 50-75 hours to the end of Stage I and anywhere from 50-150 hours for Stage II, depending on the number of alternatives considered. This is now re-programmed for an augmented 650 which will run this program in about one-fifth the time. However, studies of this magnitude definitely indicate the use of a so-called "Large Sized Computer."

## PROBLEMS OF THE PROGRAM

Here I would like to say a word about the problems of administering such a program. The gathering of data, the analysis and model building activities are extensive and require experienced personnel both of an OR and Operating Engineering type. The education and training requirements for this approach to planning are not only internal but also upwards to management and downwards to the operating personnel. The modification of existing procedures to obtain data and implement decisions are quite extensive, despite all the precautions taken to limit these.

I am quite sure that if we had been faced with training additional personnel to operate and program a computer, aside from the problem of selection of hardware, our task would have been much more difficult, if not impossible. The use of a consultant to supply additional specialists, train existing personnel, and provide programming and computational facilities has paid dividends. We have been able to develop successful planning techniques that have successively required use of small, medium and large-scale computers without ever having to face the problem of choosing or committing ourselves to the use of any one. During the developmental stages of a program of this type, where requirements are continually changing, I certainly would recommend serious consideration of this approach.

## SUMMARY

This paper is intended to illustrate how an Operations Research approach using modern scientific technology and electronic computation facilities can be applied to an operating situation. This allowed a critical examination of the operation that would not have been possible by conventional means and resulted not only in improved planning and on-the-spot savings, but also established a system whereby the company can continue to profit from these methods.

What has been accomplished? Through improved planning and control of the operations, management has been given, in readily understandable terms, alternative strate-

gies of operation properly evaluated and optimized to aid them in deciding on the best operating strategy. Departmental objectives were then defined to achieve this strategy. These objectives were detailed in the same form as existing procedures so that they could be readily implemented and controlled.

In Peter Drucker's book, *America's Next Twenty Years*, he indicated that improved understanding of the "Business System" will be essential if industry is to achieve the innovations necessary to maintain the high level of production that will enable us to enjoy an ever-increasing standard of living.

As new management skills develop, and larger computer facilities are available, we hope to improve our present methods; the costs of this effort are extremely large and as operations are improved, the ultimate payoff will only come through full automation, not only of the operating facilities, but also of the management, planning and control processes.

Automation in this form will require the establishment of a new business system. Management will have to recognize this and implement it to the fullest extent.

By integrating the existing personnel with this and using modern computation aids, it should be possible to achieve a balance of capital and operating programs to achieve more efficient operations resulting in reduced expenses that will justify the higher cost of improved management planning and control.

# The Design of a Force Platform for Work Measurement[1]

*by* **JAMES H. GREENE**[2]

*Associate Professor of Industrial Engineering, Purdue University*

*and* **W. H. M. MORRIS**[3]

*Assistant Professor of Agricultural Economics, Purdue University*

FROM the time of Taylor to the present, Industrial Engineers have been striving to improve work methods in a scientific manner. One of the most recent and interesting techniques for evaluating work has been Lauru's "effort detector" (3). This force-sensitive instrument detects and records forces exerted by a worker occupying a platform.

It is contended that direct interpretations can be made from the recordings to indicate which is the one best way to do a task. This is an idea that requires considerably more research before being fully accepted, but the authors have made some interesting correlations between platform recordings and physiological costs.

It is not the purpose here to argue the interpretations, but to discuss the design and construction of a Force Platform, Figure 1, for those wishing to pursue this interesting approach to work measurement. The design of this platform is entirely different from any other platform built to date. In operation it has proved to be very relia-

FIG. 1. Force Platform.

[1] This study forms part of the Purdue Farm Cardiac Project, AES Project No. 712, leader Dr. L. S. Hardin, sponsored by Indiana Heart Foundation and American Heart Association. Authorized for publication as Purdue University Agricultural Experiment Station paper #1269.

[2] This material is extracted from the Ph.D. dissertation of the senior author which was presented in partial fulfillment of the requirements of the Department of Industrial and Management Engineering, State University of Iowa; Chairman, Professor J. Wayne Deegan.

[3] The authors acknowledge the assistance given in this study by: J. B. Liljedahl, Agricultural Engineering Department, Purdue University; S. K. Suddarth, Forestry and Conservation Department, Purdue University and A. S. Hall, Mechanical Engineering Department, Purdue University.

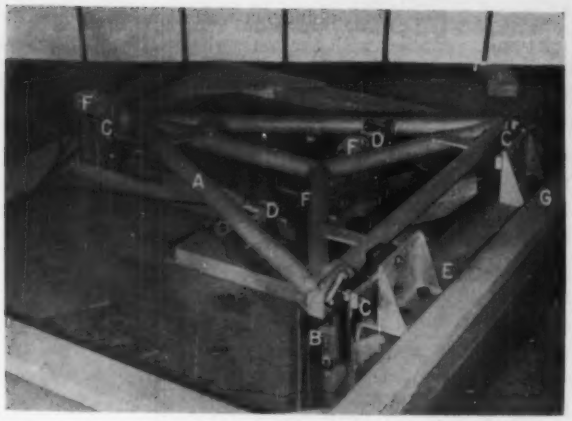



FIG. 2. Structural Characteristics of Force Platform.

ble, showing few undesirable qualities which might be expected of an initial design.

## STRUCTURAL CHARACTERISTICS

It will be useful first to show in preview the structural characteristics, Figure 2, of the completed platform. The worker is supported on a sheet of plywood in the shape of an equilateral triangle which is covered with a rubber mat. The plywood is supported by a platform frame, A. This framework is in turn supported at the corners by steel ball bearings resting on aluminum cantilever beams, B. Horizontal movement is restricted by two sets of beams, "the frontal," C, and "the lateral," D, also acting through steel ball bearings. A steel subframe, E, supports the beams. Three sensing cells, F, detect the forces exerted on the platform (G is a test frame used in calibrating the platform).

In the design of the platform it was first necessary to estimate the maximal loads in the three directions, as well as to determine the maximal frequency of movement. This information was obtainable from several excellent compilations of anthropometric measurements for large populations. The vertical forces were of most concern because the platform beams had to be designed so that each could support almost the whole vertical force and still be flexible enough to activate the sensing elements and yet remain within the elastic limit. Horizontal forces were of concern primarily to the extent that they did not upset the vertical readings. It was quite easy to obtain beams to resist the horizontal forces and still be flexible enough to activate sensing elements.

The platform frame consists of a Y-shaped structure of two-inch tubular steel. The sides of the Y are bridged by thirty-two inch long tubular steel pieces welded to form an equilateral triangle. The tubular framework supports the one-half-inch thick plywood platform, the working surface of which is covered with corrugated rubber matting.

Supporting the beams is the Y-shaped steel sub-frame made of two four-inch channel sections welded together to form a boxlike structure. The framework is strengthened by additional struts welded across the legs of the Y. The entire framework is bolted to a heavy concrete slab-floor by five one-half-inch diameter cap screws.

The deflection beams are of high strength aluminum. Aluminum, because of its low modulus of elasticity will show a greater deflection than steel under the same load. The original beam sizes were determined by calculation, but it was later found better to select the beams by experimental trial and error. This was because the relationship between beams and sensing cells and between sensing cells and recording devices was not readily obtainable. The experimental method of adjusting the beams can be done quite quickly by moving the beam clamps from one set of holes to another changing the length of the cantilever or by changing the beams if necessary. For fine adjustments of the length of cantilever, each beam is backed by an easily adjusted one-eighth inch steel shim. Each ball bearing rolls on a triangular piece of hardened steel.

Because of the adjustable triangular steel plates at each ball contact, many hours of expensive machining were eliminated. The rolling contact surface of each triangular plate was finished with a small surface grinder. Each plate pivots around a steel ball that is partially recessed in the plate and platform. Fine thread cap screws passing through the plate at each corner and screwed into the platform frame serve as adjustment screws. These plates not only remove the necessity for machining the whole platform but also allow minor adjustments to make the plates parallel to the beams necessitated by irregularities in the beam supports, etc.

The rolling balls of the horizontal beams are held in place by the heads of cold upset cap screws screwed into the beams. The adjustment screws which have been hardened and ground give a convenient means of prestressing the beams.

## METHODS OF SENSING AND RECORDING THE FORCES

The piezo-electric transducer as used in the Lauru platform was not considered ideal for this application. These crystals are used to detect oscillatory forces and the signal generated decays at a rate that would be significant under the conditions of operation of the force platform. In addition, the influence of temperature and

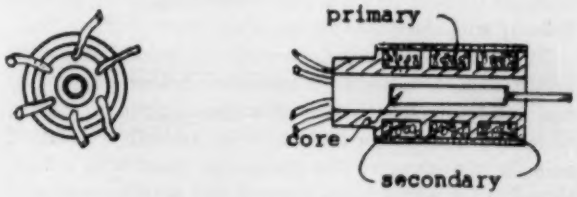



FIG. 3. Linear-Variable Differential Transformer—LVDT.

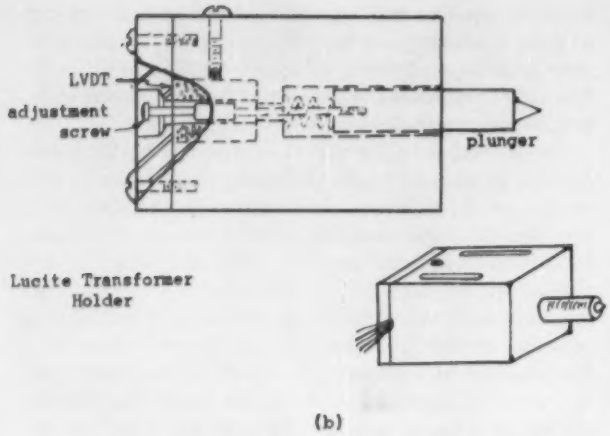



FIG. 4. Linear-Variable Differential Transformer and Holder.

humidity as well as the crystal's fragility and cost were considered in the decision to use some other transducer.

A promising transducer which has been used in the construction of force platforms is the electrical resistance strain gage which is so widely used as a measuring device in structural and mechanical stress analysis. Recording equipment is readily available for use with strain gages and numerous examples of gage applications are available in scientific literature. However, the beams with strain gages sensing bending have to be too flexible to obtain the required sensitivity thus giving a "mushy" feeling to the platform. In addition, the beams to which the gages were to be attached had to remain in a pre-stressed condition which is likely to cause the gages to "creep" and thus change the platform calibration.

The Linear Variable Differential Transformer used as the sensing elements on this platform consists of three coils of wire wound coaxially on an insulated spool, Figure 3. A magnetic core, to which the displacement is applied, is free to move along the axis of the coil. The center coil is energized with alternating current furnished by the A.C. bridge amplifier. This causes a magnetic flux to be produced linking the central primary coil with the secondary coils through the movable magnetic core. The outer coils are connected so that the voltages induced in them by the mutual flux oppose each other. For the center core position, the voltage balance for the combined output of the secondary coils is very small. This position is called the balance point. For other positions of the core, the voltages induced into the outer coils differ in magnitude, linearly with the displacement of the core.

To retain and protect the transducer and also to permit adjustment, a universal transformer holder (Figure 4) was constructed, consisting of a clear plastic housing in which the transformer is clamped in line with the reamed hole for the plunger. The plunger is fitted with a fine-thread screw which holds the core and permits necessary adjustments. On the end of the plunger is mounted the writing point of a ball-point pen which makes an almost frictionless contact with the active beam. The ball-point isolates the plunger from all angular forces. Details of the frontal cell and beam can be seen in Figure 5.[4]

A suitable recording instrument for the platform is the Brush Universal Analyzer. The Analyzer consists of a tuned 2000 c.p.s. oscillator driving the primary of the transformer; the output of the transformer is fed through an attenuator adjusting-circuit and amplifier. This in turn feeds the magnetic oscillograph which consists of the galvanometer-driven recording pen tracing a line on a motor-driven chart paper. The recordings are made on a two and three-eighths inch wide paper strip driven by a synchronous motor which can be adjusted to produce paper speeds of five, twenty-five, and one hundred twenty-five millimeters per second. Further explanation of the application and calibration of these instruments can be found in the manufacturer's brochures.

## ANALYSIS OF THE DYNAMIC CHARACTERISTICS OF THE PLATFORM

Up to this point no attempt has been made to explain the relative position of the sensing cells which is so important to the functioning of the platform.

The schematic diagram of the Force Platform is shown in Figure 6. As explained previously, a 32 inch equilateral triangular platform supports the subject. The platform is in turn supported by three cantilever beams, one at each corner. The connection between the platform and beams is through steel balls which are free to move on adjustable steel plates so that only vertical forces are transmitted at $F_1$, $F_2$, and $F_3$. The horizontal movement of the platform is restricted by two sets of cantilever

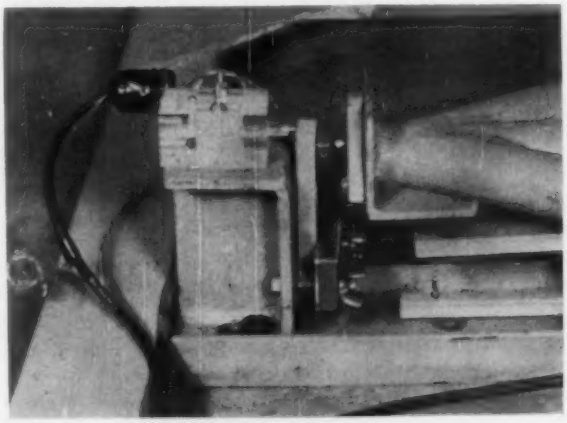


FIG. 5. Frontal Cell and Beam.

[4] To eliminate the effect of localized bending in the platform an auxiliary frame was suspended below the platform frame for the purpose of activating the sensing cell. Although it shows in the pictures and diagrams, it was not found necessary in actual practice. The sensing cell contacted the platform frame directly.

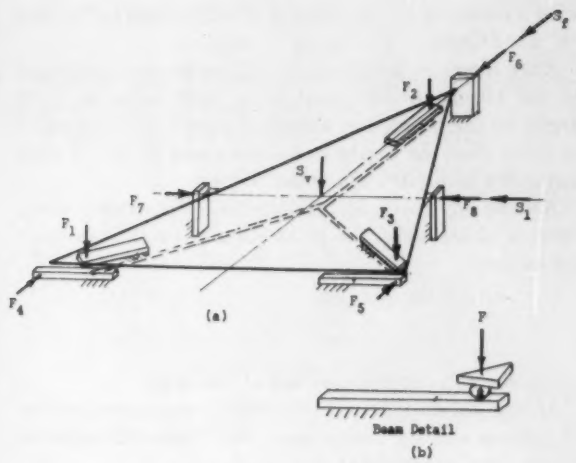



FIG. 6. Schematic of Platform.

beams. $F_7$ and $F_8$ restrict "lateral" movement and $F_4$, $F_5$, and $F_6$ restrict the "frontal" movement as well as limit the rotation of the platform.

Each beam is in effect acting as a spring and the measurements of force are in reality measurements of deflection conforming to the fixed end beam equation. For each of the three axes, vertical, lateral and frontal, the amount of deflection is translated to a voltage change by the Linear Variable Differential Transformers mounted at $S$ vertical, $S$ lateral and $S$ frontal.

Any force must be resolved into its three orthogonal components. It is essential that the forces detected in each plane are independent of any other force or movement. There must be no interaction between forces along one orthogonal axis and those on another. The ensuing discussion includes the design and proof of the geometrical characteristics of the platform and covers in turn the vertical, frontal and lateral movements of the platform.

## VERTICAL FORCES

As shown in Figure 6b, the platform has an adjustable triangular plate at each corner which is free to move on a steel ball bearing which is in turn free to move on the beam. Since the balls are free to move they cannot transmit any appreciable horizontal forces. Therefore, the only force acting on these beams is vertical. As the beams can detect only vertical forces it is essential only to show that horizontal forces can in no way have vertical components.

Simplifying the explanation, Figure 7a, by placing the force, $W$, on a line between $R_1$ and $R_2$ and considering a simple beam the following expressions can be made.

$$F_y = 0 \qquad F_x = 0$$

$$R_1 + R_2 - W = 0 \qquad F_x = R_h$$

This in itself is proof that $R_1$ and $R_2$ are uninfluenced by horizontal forces.

Next it is necessary to show that one sensing cell placed at the center of the equilateral platform (Figure 7b) will sense the true value of any force, $W$, regardless of its location within the triangle of the platform, assuming of course that all vertical beams are similar.

Any weight, $W$, on the platform at a distance $c$ and $d$ from the two edges (1-2),(1-3), will deflect points 1 and 2 by the amount of $\Delta_1$ and $\Delta_2$. $\Delta P$, midway between 1 and 2, will be deflected:

$$\Delta P = \frac{\Delta_1 + \Delta_2}{2}$$

Passing a section through $P$-3, it can be seen that the depression of $c_g$ by $W$ is:

$$\Delta c_g = \frac{2}{3}\left(\frac{\Delta_1 + \Delta_2}{2}\right) + \tfrac{1}{3}\Delta_3$$

Note that $c_g$ can be shown as $\frac{1}{3}$ of $L$, from $P$ and $\frac{2}{3}$ of $L$, from 3 on the line $P$-3.

$$\Delta c_g = \frac{\Delta_1}{3} + \frac{\Delta_2}{3} + \frac{\Delta_3}{3}$$

$\Delta_1$, $\Delta_2$, and $\Delta_3$ can be expressed as the function of the spring constant, $K$, and the reaction, $R$.

$$\Delta_1 = \frac{R_1}{K} \qquad \Delta_2 = \frac{R_2}{K} \qquad \Delta_3 = \frac{R_3}{K}$$

Therefore

$$\Delta c_g = \frac{R_1}{3K} + \frac{R_2}{3K} + \frac{R_3}{3K} = W/3K$$

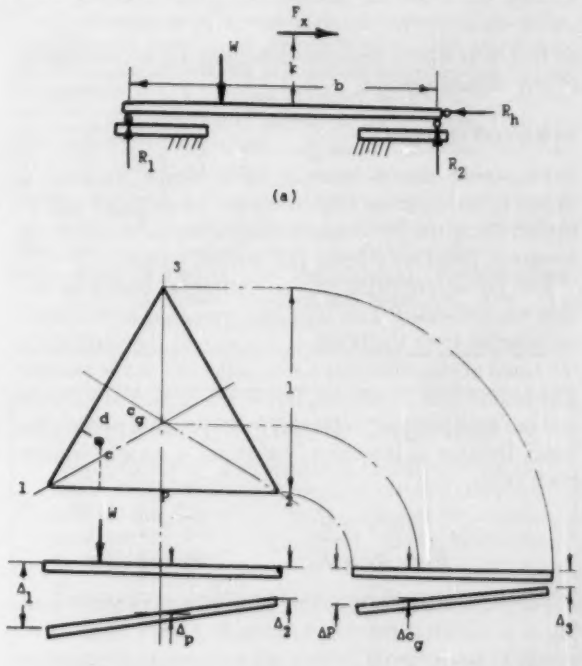



FIG. 7. Vertical Force Analysis.

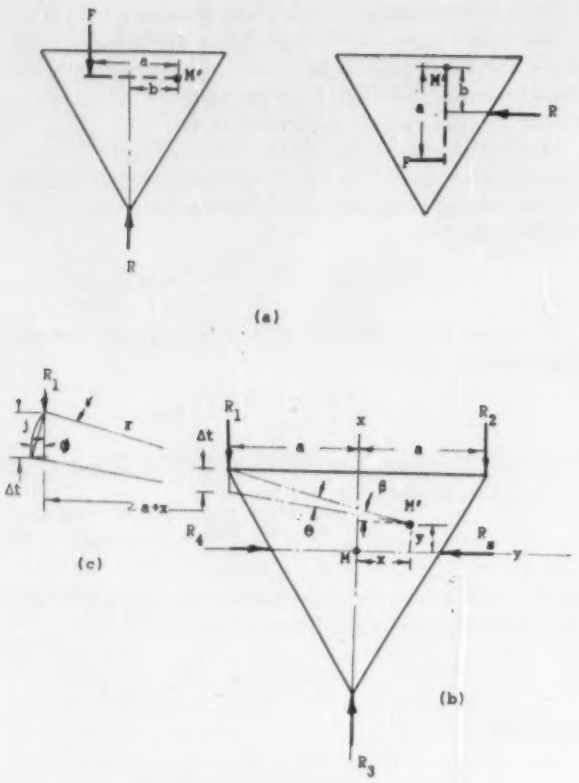



FIG. 8. Horizontal Force Analysis.

so that it is shown that the deflection $\Delta c_y$ is independent of any distance, $d$ or $c$.

**HORIZONTAL FORCES**

The proof that horizontal force beams, situated as shown in the diagram (Figure 8) will be deflected only by the forces in the direction desired, is not as direct as the foregoing proof concerning the vertical forces.

The initial condition of the horizontal beams is that they are preloaded. This is necessary so that as the load is transferred from the beam at one side of the platform to the beam at the other side a zero point will not be reached. The beams must, therefore, follow the motion at all times and the steel balls are retained by the residual pre-loading force. Because of this initial condition, a state of equilibrium exists:

$$\Sigma F_x = 0 \qquad F_y = 0$$

$$R_1 + R_2 = R_3 \qquad R_4 = R_5$$

For the sensing cells, $S_f$ and $S_i$ to give the correct reading it is essential for the platform to have a point of rotation at its center $M$, which remains constant regardless of where a force, $F$, is applied. This becomes obvious in Figure 8a as the force, $F$, is moved along the moment arm with a center at $M$ the value of $R$ will change as "a" and "b" are altered.

Since forces on the platform (Figure 8) are transmitted to the beams through steel balls, only forces at right angles to the beams are sensed. However, it is necessary to prove that the platform rotates about $M$ rather than any other point, $M'$. The proof follows.

Assume any point, $M'$, (Figure 8b) at position $x$ and $y$ from $M$ about which the platform might rotate an angle $\Delta\Theta$ radians.

$$\frac{\Delta R_1}{\Delta t} = K_1$$

where $K_1$ is the spring constant of the beam.

$\Delta t$, can, for all practical purposes, be expressed in terms of radians and the radius since the length of the arc is nearly equal to the chord.

$$\Delta t = \Delta\theta(a + x)$$

From Figure 4c

$$\frac{j}{r} = \Delta\theta \text{ radians}$$

$$= r\Delta\theta$$

$$\frac{\Delta t}{j} = \cos\phi$$

$$\phi = \beta \begin{cases} \phi + \gamma = 90^\circ \\ \beta + \gamma = 90^\circ \end{cases}$$

$$\Delta t = j \cos\beta$$

$$\Delta t = j \times \frac{a + x}{r}$$

$$\Delta t = \frac{a + x}{r} \times r\Delta\theta = \Delta\theta(a + x)$$

and it follows:

$$\Delta R_1 = \Delta\theta(a + x)K_1$$

similarly

$$\Delta R_2 = \Delta\theta(a - x)K_2$$

$$\Delta R_3 = \Delta\theta \times K_3$$

$$\Delta R_4 = \Delta\theta y K_4$$

$$\Delta R_5 = \Delta\theta y K_5$$

Proving that $y = 0$ it follows that for equilibrium:

$$\Sigma F_y = 0$$

therefore:

$$\Delta R_4 + \Delta R_5 = 0$$

by substituting equations 4 and 5

$$\Delta\theta y K_4 + \Delta\theta y K_5 = 0$$

$$y(K_4 + K_5)\Delta\theta = 0$$

Since the equation is equal to zero and the spring constant is the same, $y$ must equal zero.

To prove that $x = 0$, it follows that for equilibrium

$$\Sigma F_x = 0$$

$$\Delta R_1 + \Delta R_2 + \Delta R_3 = 0$$

substituting equations 1, 2, and 3

$$\Delta\theta[(a + x)K_1 - (a - x)K_2 + xK_3] = 0$$

$$\Delta\theta[x(K_1 + K_2 + K_3) + a(K_1 - K_2)] = 0$$

$$x = \frac{-a(K_1 - K_2)}{\Delta\theta(K_1 + K_2 + K_3)}$$

and since $K_1 = K_2$

$$K_1 - K_2 = 0$$

and it follows that

$$x = 0$$

Therefore, the platform is only free to rotate about $M$, the centroid of the equilateral triangle.

## CONCLUSIONS

This being an initial design, no attempt has been made by the authors to give complete construction data for the platform; it is expected that each new platform will contain improvements conceived by the group of people involved in its construction.

The platform illustrated was subjected to an extensive series of tests and the force response curve for all axes is linear within very narrow limits. There is no evidence of interaction between axes. The sensitivity exceeds all experimental requirements. In fact, the platform appears sensitive enough to detect the human heart beat of the subject.

## REFERENCES


(1) Lauru, L., "Etude Physiologique des Pedales de Commande pour Presses a Decouper et a Emboutir," *Trav. u. and Sec.*, September, 1954.

(2) Lauru, L., "Introduction de la Mesure dans l'Etude et la Simplification des Mouvements," *Travail et Methodes*, pp. 27-35, December, 1953 and pp. 27-37, January, 1954.

(3) Lauru, L., *The Manager*, Volume 22, Number 5, Management Publications, Limited, London, May, 1954.

(4) Lauru, L., "Nouvelle Methode d'Etude du Travail de l'Homme," *Communications a l'Academie des Sciences transmises.*

(5) Lauru, L., "Physiological Study of Motions," *Advanced Management*, Vol. 22, No. 3, pp. 17-24, March, 1957. (Translated by Lucien Brouha.)

(6) Lundquist, Elmer C., *Electrical Resistance Strain Gages Applied to Wind Tunnel Balances*, Institute of the Aeronautical Sciences, New York, November 20, 1946.

(7) McFarland, Ross, A., and Others, *Human Body Size and Capabilities in the Design and Operation of Vehicular Equipment*, Harvard School of Public Health, Boston, 1953.

(8) Pankhurst, R. C., and Holder, D. W., *Wind Tunnel Techniques*, Sir Isaac Pitman and Sons, Ltd., London, 1952.

(9) Perry, C. C., and Lessner, H. R., *The Strain Gage Primer*, McGraw-Hill Book Company, Inc., New York, 1955.

(10) Pope, Alan, *Wind Tunnel Testing*, John Wiley and Sons, Inc., New York, 1947.

(11) Schaevitz, H., "The Linear Variable Differential Transformer," *Proceedings of the Society for Experimental Stress Analysis*, Vol. 4, No. 2.

(12) Woodson, Wesley E., *Human Engineering Guide for Equipment Designers*, University of California Press, Berkeley, California, 1954.

(13) The Brush Development Company, Instrument Division, *Operating Instructions for Model B. L. 320, Universal Analyzer.*

(14) Tufts College Institute for Applied Experimental Psychology, *Handbook of Human Engineering Data for Design Engineers*, December, 1949.



***Just Published***

**CONTROL ENGINEERING HANDBOOK**

**Edited by Byron K. Ledgerwood and the Staff of *Control Engineering***

***Large size 8½ x 11 pages, 200 illustrations, $7.50***

THIS practical working manual brings you step-by-step practices and procedures on all aspects of control engineering and design. You are guided every step of the way through system specification, synthesis and analysis, and evaluation. You get a complete run-down on pneumatic and mechanical control-function generators, servo wiring design, ac analog computers, and nonlinearities in control systems. Covers control systems engineering in both modern industry and the military, from the basic fundamentals to putting systems into actual practice.

**Authoritative**
Drawn from articles that appeared in *Control Engineering*, this manual helps you benefit from the experience and know-how of experts from many leading companies in this field.

**Order from: JOURNAL OF INDUSTRIAL ENGINEERING**
**A. French Building, 225 North Ave., N.W.**
**Atlanta 13, Georgia**

**CHIEF INDUSTRIAL ENGINEER**

Required for a large Southern California manufacturer. This excellent position involves responsibility for fabrication methods, assembly planning, manpower control, plant layout, selection of facilities, etc.

Salary open; relative experience on management level a must.

Box R, Journal of Industrial Engineering, 225 North Avenue, Atlanta 13, Georgia.

# The Independence of Pace Rating Versus Weight Handled*

*by* C. B. GAMBRELL, JR.

*Assistant Professor, Department of Industrial Engineering, Purdue University*

THE activity in business, government, and industry which is responsible for determining time standards for worker performance is commonly known as Time Study. The research described in this article is concerned with an investigation of the rating phase of time study.

Most time study systems in use today attempt to rate operator performance by using the technique of *performance rating* (1, p. 370). This rating procedure is one which requires the analyst to consider the following three things simultaneously:

1. The speed or tempo of operator movement.
2. The job difficulty.
3. Environmental and other conditions of the job.

An evaluation of this type depends completely upon the judgment of the analyst and his ability to relate what he observes to what he thinks he would have seen if he had observed a normal performance. The subjectivity of this procedure has led to many difficulties.

Two prominent people in Industrial Engineering (6) (9) have recognized the seriousness of the rating phase of time study and have proposed systems for removing or reducing to a minimum the degree of subjectivity involved.

Actually, the two systems are almost identical because each requires that:

1. Rating be done and that it be based only on pace, speed, or tempo of movement.
2. Secondary adjustment values be used to adjust the rating depending upon the difficulty of the job.
3. Films be used to record bench-mark paces.
4. Films be used to train and refresh the analyst's concept of pace.

The only difference in the two systems which this author can establish is that of degree, for where Nadler provides eight secondary adjustment categories with specific values, Mundel provides for only six categories with specific values.

In view of the extreme similarity of these two systems they will both be referred to hereafter in this work as *objective rating*. Where specific attention is made it will be limited to the system proposed by Mundel because:

1. He was the originator of the system.
2. His system probably has greater industrial use.

The system of objective rating consists of two steps:

1. The rating of observed pace against an objective pace-standard, which is the same for all jobs.
2. The use of a secondary adjustment (to this pace rating) consisting of a percentage increment, added after the application of the numerical appraisal from step 1 has been used to adjust the original observed data (for job difficulty) (7, p. 373).

Further comments concerning the above steps are:

1. In this rating, no attention whatsoever is paid for by the rater to job difficulty and its limiting effect on possible pace; hence, a single pace-standard may be used instead of a multiplicity of mental concepts.
2. This percentage increment is to be taken from experimentally determined tables of the effect of various observable factors that control the exertion required at a given pace (7, p. 373).

Execution of this procedure permits one to arrive at a time equivalent to normal time which is actually standard time less allowances.

The theory behind this system is that any deviation from the bench-mark pace-standard, which involves no difficulty, is due either to the operator or to job difficulty. Objective rating, by comparison with a standard film loop, can correct for operator effects. Therefore, the only remaining effects to be corrected for are those involving job difficulty.

The use of the system, as described, depends upon the ability of the time study analyst to avoid self contamination from the influence of the difficulty of the job, while at the same time attempting to determine a pure pace rating for the job. If the job difficulty influence cannot be separated from the rating of pace then, some portion of the difficulty is likely to be accounted for twice. It is not desirable to permit this condition to exist unless it is known to what degree the job difficulty influences the pace rating and proper correction is made for it.

The adjustment values for weight go as high as 82% for an arm lift of fifty pounds and as high as 44% for a leg lift of forty-four pounds (7, p. 398). Thus, an arm lift

* Based in part upon a Ph.D. dissertation completed by the author in 1958, Department of Industrial Engineering, Purdue University.

of fifty pounds equals nearly twice the amount (48%) of adjustment provided for the most extreme conditions of all other five secondary adjustment categories combined. Therefore, it appears that the most significant adjustment category is *weight* and that an error in applying these values could be serious.

However, all time study work involves the validity of the rating problem, because all time study relies upon rating as one of its basic ingredients. No time study system is better than its rating procedure. There are those who have recognized that objective rating is, to a considerable degree, based more upon fact than any of the other rating systems in use. The problem which needs to be solved, therefore is: *How valid is the assumption that time study people can rate pace and that they are not influenced by job difficulty during the rating process?* Until this question is answered, the validity of objective rating will be in doubt.

The purpose of this research was to investigate the influence of the job difficulty category "weight" upon the pace ratings of a filmed job by several experienced, currently practicing time study analysts, who were well trained in the objective rating system.

## METHOD

*Apparatus.* Films of an experimental task were used in this research. The use of film was based on the assumption that they present the same perceptual stimuli to the rater as does the actual operation. This use is one of the requirements for performing step one of objective rating (7, p. 377). The validity of this assumption has been confirmed by one researcher, Margolin (4) and rejected by two others, Nadler (8) and McGuire (5). This research does not attempt to further confirm or reject this point, but used films as a prescribed requirement for performing objective rating.

A box handling job was designed to incorporate specific desirable test conditions for investigation purposes. It represented an activity which is often found in warehousing operations. The performance of this job was filmed, in order that data could later be collected from analysts in the field. The work assignment required an operator to move individual boxes two and one-half feet while lifting them one-half foot from one gravity feed conveyor to another. The conveyors were at right angles to each other such that the operator always stood in one place. This method was established as the Standard Operating Procedure for the experiment regardless of the weight of the box moved. Recognizing that this job required primarily an operator arm lift, weights were chosen such that a distinct difference would exist in weights chosen, from light to heavy, and still attain a reasonable coverage of weights found in Mundel's weight range. Four weights ($W$): five, ten, twenty, and forty pounds, were chosen for investigation purposes. These specific weight values were chosen in order to ascertain curvilinear trends by means of orthogonal polynomials. Also, recognizing that the size ($S$) of container (box) used might possibly have some influence upon the analyst, and since Mundel's system makes no adjustment for size, four box sizes were selected at random from an industrial firm for use in the experiment. The volume of these boxes was: 0.45, 0.61, 0.92, and 1.53 cubic feet respectively.

The choice of an additional factor, pace ($P$), was necessary to make the job design complete. Several articles have appeared in technical journals in recent years concerning the ability of an analyst to detect different paces. At least one study, Lifson (3), confirms that analysts tend to rate slow paces faster and faster paces slower. Therefore, a range of paces was selected to run from slow to fast in terms of cycle time. Cycle times of .03, .035, .04, and .05 minute were chosen for pace representation.

The job was set-up for performance and filming in a dry goods storage warehouse and involved the movement of boxes in conformance with the standard operating procedure previously described. A tape recorder was placed near the operator and used to reveal the pace rhythm to the operator. The cycle terminal points were recorded on the tapes for each pace in terms of an instantaneous shrill sound. The four paces were played on the recorder as needed for the sequence to be performed.

The operator for the filmed job was chosen because he was accustomed to performing work of this nature. He was five feet ten inches tall, weighed one hundred sixty pounds and was considered to be in excellent health and physical condition. He was trained for the job and otherwise made familiar with all phases of the task procedure. Special attention was given to his maintaining a constant pace as revealed by the tape recorder sounds.

The job was performed and filmed according to a prearranged sequence for operator and set-up convenience. This sequence began with the heaviest weight first. Then the lighter weights of twenty, ten, and five pounds respectively were used following the same sequence for each until all sixty-four combinations had been filmed.

A film loop was made for each of the sixty-four scenes for the job. Prints were made from each loop in sufficient footage to permit a presentation of continuous showing. Film titles, analyst instructions, scene numbers, etc., were also filmed for inclusion in a master film.

The sixty-four job performances were arranged in the master film according to random order such that any similarity in successive scenes would be due to chance alone. Early in the research the question arose as to how long a trained analyst needed to observe a filmed record of job performance before he felt able to assign a rating value to the performance. A review of the literature revealed only one research study (2, p. 162) with necessary viewing time as its objective. In the study Barnes raises the question as to

> . . . what effect the shortening of observation time has on the ability of the observer to rate performance (2, p. 162).

From the results of his study, Barnes concluded that:

> . . . there is at least some basis for believing that variations in the length of observation time, within practical limits, does not have a very great effect on performance ratings (2, p. 163).

Recognizing that the type of work viewed and rating system used might have some effect upon application of Barnes' results with card dealing, a pilot study was run at an industrial concern in Kokomo, Indiana, to determine the time required by their raters who used *objective rating* to arrive at pace ratings for film viewed job performances.

Results of this pilot study revealed that an exposure period of at least 0.75 minute was required in order to be 99.7% confident that the analysts had sufficient time to mentally rate the observed performance. Therefore, a film running time per scene of 0.75 minute was used in the master film.

## SUBJECTS

It was assumed that the best data which could be used in an experiment of this kind would come from industry. Therefore, arrangements were made to collect data in two plants using the objective rating system. Seven analysts from Plant A, a meat packing plant, and twelve analysts from Plant B, a producer of aluminum kitchen ware, were selected to serve as subjects in this experiment.

Objective rating had been used in both of these plants for approximately four years. Extensive use of their own multi-image loop was made both in the training of analysts and in rating refresher sessions for trained analysts. Although rating refresher sessions were held once a month in each plant, analysts selection, training, and control were more thorough and comprehensive at Plant A than at Plant B.

## PROCEDURE

*Data Collection.* Projection of the film for data collection was at the same constant rate (1,000 fpm) at which it was filmed. The data were collected in the same manner at each plant as follows:

1. Their own multi-image loop was projected for as long as necessary for the analysts to completely refresh themselves on the various pace levels.
2. Projection of the first one-half of the master film began.
3. Refreshment break at about the half way point of the film.
4. Projection of the last half of the master film.

The experimenter then collected the completed data sheets and answered questions from the group.

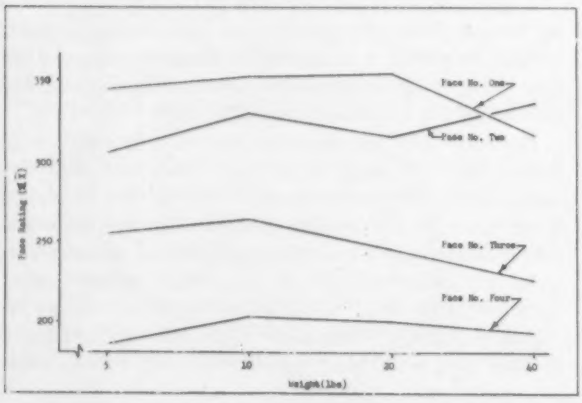



FIG. 1. Pace-Weight Interaction for Plant A, Box Handling Individual Data Analysis.

*Data Analysis.* The data were analyzed using the Analysis of Variance technique in order that inferences could be drawn concerning the experiment's main effects and the main effect interactions. The measured variable used in the experimental design was a cell value representing an individual pace rating from each analyst for the cell condition of weight, size, and pace. Therefore, analysts are introduced as a main effect, thus permitting conclusions to be drawn about their rating performance.

The population mathematical model for analysis purposes was:

$$\begin{aligned} Y_{ijklm} = \mu &+ \alpha_i + \beta_j + \alpha\beta_{ij} + \gamma_k + \alpha\gamma_{ik} + \beta\gamma_{jk} \\ &+ \alpha\beta\gamma_{ijk} + \delta_l + \alpha\delta_{il} \\ &+ \beta\delta_{jl} + \alpha\beta\delta_{ijk} + \gamma\delta_{kl} + \alpha\gamma\delta_{ikl} \\ &+ \beta\gamma\delta_{jkl} + \alpha\beta\gamma\delta_{ijkl} + \epsilon_{m(ijkl)} \end{aligned}$$

where

$Y$ denotes the analyst's response to the experimental stimuli
$\mu$ denotes the true response of the over-all mean
$\alpha$ denotes the effect due to pace ($P$)
$\beta$ denotes the effect due to weight ($W$)
$\gamma$ denotes the effect due to size ($S$)
$\delta$ denotes the effect due to analysts ($A$)
$\epsilon$ denotes the effect due to experimental error
$i$ denotes the number of levels of $P$
$j$ denotes the number of levels of $W$
$k$ denotes the number of levels of $S$
$l$ denotes the number of levels of $A$
$m$ denotes the number of replications

Analysts were considered as random and qualitative and the four way interaction $P \times W \times S \times A$ was assumed to be zero since only one replication was planned.

A test to determine homogeneity of variance within each cell, that is, the seven analysts from Plant A or the twelve analysts from Plant B, was not considered to be appropriate since each sample contained the same set of analysts and the samples were therefore not independent. Thus, stratification of the sample would have resulted because of the tendency of a particular rater to continue to rate high or low. This feature would tend to inflate the range ($\overline{R}$) and cause the data to be in control, because $\overline{R}$ would include not only chance causes but also any assignable difference between raters.

TABLE 1

*Analysis of Variance*

Plant A, Box Handling—Individual Data

| Source of Variance | df | M.S. | F obs |
|---|---|---|---|
| Pace ($P$) | 3 | 31,996.01 | 169.70** |
| Weight ($W$) | 3 | 485.44 | 11.27** |
| Size ($S$) | 3 | 85.47 | 2.96 |
| Analysts ($A$) | 6 | 452.32 | 18.94** |
| Pace×Weight | 9 | 300.77 | 7.66** |
| Pace×Size | 9 | 68.71 | 2.51* |
| Pace×Analysts | 18 | 188.54 | 7.90** |
| Weight×Size | 9 | 58.15 | 1.75 |
| Weight×Analysts | 18 | 43.08 | 1.80* |
| Size×Analysts | 18 | 28.90 | 1.21 |
| $P\times W\times S$ | 27 | 68.23 | 2.86** |
| $P\times W\times A$ | 54 | 39.25 | 1.64* |
| $P\times S\times A$ | 54 | 27.35 | 1.15 |
| $W\times S\times A$ | 54 | 33.25 | 1.39 |
| Error | 162 | 23.88 | |
| | 447 | | |

* Significant at the 5% level.
** Significant at the 1% level.

## RESULTS

The results of this research, Tables 1 and 2, indicate that the secondary adjustment category investigated, *weight*, did influence the pace ratings of some analysts to such a degree that the variability was statistically significant. This is to say that the variability was great enough that by chance alone it could not be expected, for example, to happen one time in a hundred if the same experiment were repeated. Further, it was found that another component of the job environment, size of the object being worked with, had a statistical significant influence on the analysts' pace ratings. A discussion of the main effects and main effect interaction follows.

*Pace.* The paces presented were evaluated by the analysts as being significantly different. This was true at the 1% significance level at both plants. Further, a Newman-Keuls Test (10) showed that each pace was evaluated by the analysts at both plants as being different from all other paces. The experiment was designed in order that there would be differences in all paces. Since the analysts detected this, it is evident that these analysts can recognize a change in work pace of the nature presented for the task of handling boxes.

*Weight.* Weight had a significant influence on the pace rating of the analysts at Plant A, but did not at Plant B. Therefore, this raises a question concerning the use of weight as a separate adjustment category. To do so assumes that the analysts are not already correcting, at least in part, for weight in their pace ratings. Further, a Newman-Keuls Test showed that the weights which affected the analysts most, thus causing the significant difference, were five pounds versus ten pounds and ten pounds versus forty pounds. This indicates that of all the weight combinations these two were such that the analysts were probably influenced in their pace ratings by the spread of the two.

Further analysis of the influence of weight revealed that the significance was due to the quadratic effect of the relationship of the weights presented. The interesting thing about this relationship was that the apex of the function was at the ten pound weight, which perhaps explains the effect which the ten pound weight played in combination comparisons with the other weights.

*Size.* The presentation of different size containers did not influence the ratings of the analysts at Plant A, but it did at Plant B. Therefore, the size of the object used in the job did significantly influence some of the analysts' pace ratings.

The boxes which accounted for the significance in variation were numbers three and four. Three of the six pair combinations were significantly different and two of these three involved box number three. Box number three was the only one of the four boxes which was higher than it was long or wide. The height feature of this particular box may account for the adverse influence which its size had on the pace ratings.

The significant influence of size was due to the cubic effect of the relationship of sizes presented. Analysis of this relationship revealed that it probably is a unique one for the particular size boxes used and extrapolation of the function would be risky.

*Analysts.* The results of the research revealed that there were significant differences at the 1% level among analysts at both plants in their ability to rate pace. Since the analysts participating in the experiment were considered to be random, even more variance can be expected from all of those who practice this system of rating based on evidence of the stratified sample.

These results indicate that the analysts at each plant did not rate alike or, in other words, standards set by each of the analysts for this same job would probably be different.

TABLE 2

*Analysis of Variance*

Plant B, Box Handling—Individual Data

| Source of Variance | df | M.S. | F obs |
|---|---|---|---|
| Pace ($P$) | 3 | 48,647.01 | 431.88** |
| Weight ($W$) | 3 | 264.95 | 1.56 |
| Size ($S$) | 3 | 429.40 | 11.49** |
| Analysts ($A$) | 11 | 4,072.00 | 106.21** |
| Pace×Weight | 9 | 281.43 | 6.32** |
| Pace×Size | 9 | 90.78 | 2.50* |
| Pace×Analysts | 33 | 112.64 | 2.94** |
| Weight×Size | 9 | 166.66 | 3.35** |
| Weight×Analysts | 33 | 170.37 | 4.44** |
| Size×Analysts | 33 | 37.36 | 0.97 |
| $P\times W\times S$ | 27 | 132.05 | 3.44** |
| $P\times W\times A$ | 99 | 44.50 | 1.16 |
| $P\times S\times A$ | 99 | 36.26 | 0.95 |
| $W\times S\times A$ | 99 | 49.76 | 1.30 |
| Error | 297 | 38.34 | |
| | 767 | | |

* Significant at the 5% level.
** Significant at the 1% level.

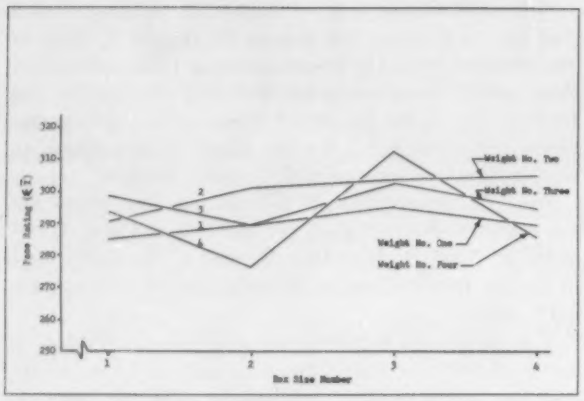



FIG. 2. Weight-Size Interaction for Plant B, Box Handling Individual Data Analysis.

*Interactions.* An analysis was made of the two-way interactions to determine, if possible, the reason for their significance. Some interesting points disclosed by this analysis were:

1. That the Pace-Weight interaction was probably significant because the analysts at both plants misinterpreted the pace due to the influence of weight for paces one and two for weight four, see Figure 1.
2. That as a result of the Pace-Size interaction the analysts did not interpret pace number two consistently with other paces so far as size was concerned.
3. That the Weight-Size interaction was probably significant because paces involving weight four and perhaps weight three were not rated as being consistent in relationship to size with respect to weights one and two, see Figure 2.

## CONCLUSIONS

The results of this research indicate that one should reject the experimental hypothesis that, *Rating Made by Skilled, Thoroughly Trained, and Practicing Time Study Analysts Using Pace Rating Are Not Influenced by Job Difficulty.* This conclusion is based on the following:

1. Weight was shown to have a significant influence on pace ratings, thus, indicating that some analysts cannot completely separate this job environmental effect from their judgment of operator pace.
2. The size of the object moved by the operator was shown to have a significant influence on analysts' pace ratings. This indicates that perhaps size is a job environmental feature which the analysts are unable to completely avoid in rating operator pace.
3. Interactions exist between analysts and job factors and between job factors themselves. This indicates that the combination of two or more factors can produce an effect on analysts' pace ratings which can be statistically significant.
4. Further analysis of the data showed that the degree of training has considerable influence on how well time study analysts pace rate. The group at Plant A did a much better job of rating than the group at Plant B did. This can be attributed to the intensive initial and refresher training program utilized at Plant A. No such formal training program existed at Plant B, although some attention was given to pace refresher work. This conclusion is supported in part by McGuire, who concluded from his research that: "Training Reduces Variability Among the Observers" (5, p. 83). However, this conclusion does not confirm another of McGuire's conclusions that the rating of motion picture film is not the same as rating actual job performance(s). His conclusion would eliminate film as a training device.
5. There is a possibility that training might also be used to overcome the influence of weight and size, because when weight affected the analysts at one plant, it did not at the other and vice versa for size. Familiarity with the work process may account for this, because at Plant A there is less manual lifting work than at Plant B. On the other hand, there is a great deal of exposure to packages of various sizes at Plant A and considerably less at Plant B. Training then might help make up the weight and size familiarization deficiency.
6. Although weight was found to be a factor which significantly influenced the pace ratings, there is no indication as to how much correction, if any, was made for this factor by the analysts. It can only be concluded that the influence of this factor which was not corrected for by the analysts caused a statistically significant difference in their ratings. As to whether this statistical significance is also a practical significance was beyond the scope of this study.
7. Further analysis of the data showed that the analysts used preferred numbers in rating when permitted to do so. The fact that the analysts at Plant A used numbers without apparent regard to preference was probably a result of their training program. They were taught to rate using 1 unit increments. No specific attention was given to this feature in the analysts training program at Plant B and the data showed that they preferred 5 unit increments centering on 0 and 5.
8. Training reduces rater variability as evidenced by the error term. It was smaller at Plant A than at Plant B.

## REFERENCES

(1) BARNES, RALPH M., *Motion and Time Study,* 4th Edition, John Wiley and Sons, New York, 1958.

(2) BARNES, RALPH M., *Work Sampling,* William C. Brown Company, Dubuque, Iowa, 1956.

(3) LIFSON, KALMAN A., "Errors in Time-Study Judgments of Industrial Work Pace," *Psychological Monographs General and Applied,* No. 355, Vol. 67, No. 5, 1953.

(4) MARGOLIN, LEWIS, "A Comparison of Two Methods of Presentation for Time Study Rating," unpublished Master of Science Thesis, Purdue University, Lafayette, Indiana, 1948.

(5) MCGUIRE, RICHARD W., "An Investigation of the Equivalence of Perceptual Stimuli in Rating," unpublished Ph.D. dissertation, Ohio State University, 1957.

(6) MUNDEL, MARVIN E., *Motion and Time Study,* 1st Edition, Prentice-Hall, New York, 1950.

(7) MUNDEL, MARVIN E., *Motion and Time Study,* 2nd Edition, Prentice-Hall, New York, 1955.

(8) NADLER, GERALD, "An Analysis of the Difference in Time Study Rating from Films of Operations and the Actual Operator," unpublished Master of Science Thesis, Purdue University, Lafayette, Indiana, June 1946.

(9) NADLER, GERALD, *Motion and Time Study,* McGraw-Hill Book Company, Inc., New York, 1955.

(10) NORTON, JAMES, "Simultaneous Significance Tests for Multiple Contrasts in the Analysis of Variance," hand-out notes, Statistical Laboratory Purdue University, 1957.

# Summary of the Industrial Engineering Symposium, the University of Iowa, November, 1958

*Reported by* **AUSTIN WESTON**

*Secretary, Long Range Planning Committee*

*and* **D. G. MALCOLM**

*Chairman, Long Range Planning Committee*

FOR the past five years AIIE has sponsored an annual two-day Symposium on Industrial Engineering. These symposia have brought together leading Industrial Engineers and interested managers in the academic, consulting, government, and industrial areas for the purpose of providing a measure of advice and guidance to the Industrial Engineering profession in its growth.

The first symposium produced the definition of Industrial Engineering which was subsequently endorsed as the official AIIE definition (1). Succeeding symposia have expanded and explained the definition to various parties interested in or affected by Industrial Engineering activities (2) and have developed typical case histories to illustrate the systems design approach in Industrial Engineering.

The most recent symposium in the series was held at the University of Iowa in November, 1958. Participants in the symposium were organized into discussion groups which were directed to develop definitive statements to the following topics:

1. The areas of opportunity for the continued growth and application of the Industrial Engineering approach.
2. Review and revision of the Industrial Engineering "Process" chart developed for an earlier symposium (3).
3. A description of the variety of tools, techniques and skills utilized in this Industrial Engineering process.

The outputs of the various groups were pooled and this report attempts to summarize the essence of discussions directed to each subject. The report concludes with the announcement of plans for the next symposium and a list of participants.

## AREAS OF OPPORTUNITY

Discussion of this subject identified areas where the Industrial Engineering profession can improve the quality of its work and extend the breadth of its application. It was felt important to set the stage for this discussion by depicting how modern management thinks of an Industrial Engineer. The consensus indicated that in addition to his traditional role in work measurement, cost studies, plant layout, etc., management now looks upon the Industrial Engineer as one concerned with:

1. Improving the performance and output of an existing system of men, machines, materials, and information regardless of whether it is in the manufacturing function (where most Industrial Engineering activities have sprung up and are concentrated) or in the budgetary, legal or sales function.
2. Improving the design of existing controlling systems.
3. Analyzing, developing, and implementing an entirely new system consistent with modern decision methods and computer technology.

Further, three trends in the pattern of the Industrial Engineer's activities were identified. The first trend noted is a shift in emphasis from action after the fact to action before the fact on the part of the Industrial Engineer, i.e. a shift from controlling or helping to control what exists to the task of *designing* improvements or innovations. Thus, in addition to developing solutions for a given problem, management is giving the Industrial Engineer opportunity to diagnose the basic problem and to search out new solutions. In this capacity the Industrial Engineer can either help find a new product, process, investment, or help in deciding when to abandon old ones.

The second trend observed is the use of the Industrial Engineer in a more creative role in support of dynamic modern business. In implementing the concepts of science and engineering, management is faced with many problems of application and acceptance nature. The Industrial Engineer is turning from the routine operation of various controlling systems to the task of speeding the installation of new manufacturing technologies and the timely acceptance of change by those affected. Support of such R&D outputs by timely Industrial Engineering analysis is producing much needed reduction in installation time for new products and processes.

The third trend lies in the increasing development of

factual and unbiased solutions based on an increased ability to measure, understand, and manipulate systems. The Industrial Engineer has an integral role, quite often the leader, on operations research or system analysis teams involved in such studies. In addition to such study, the Industrial Engineer is concerned with more than merely being responsible for the development of such solutions. He also lays the foundation for ultimate acceptance at the very outset of his work; he should keep up the promotion and stimulation of interest during his work; and, he should complete his work with a presentation which utilizes the skills necessary to secure the full understanding needed for a decision to accept and implement.

The following areas where the Industrial Engineer can directly serve management in a key staff role were identified:

1. Establishment, clarification, and modification of company objectives. The definition of mission and direction of a company.
2. Design of an organization or a system of human physical resources used to accomplish these objectives.
3. Recommendations concerning the allocation of the resources that have been organized, whether they be staff, operating, or line. This allocation must not only be initially determined but must be kept continually in balance. Here management is looking for an engineering approach in the determination of where their dollars, their human, or their physical resources can be invested for the greatest return.
4. Design of the basic system by which these resources are utilized. Included here is not only the operational system by which these resources distribute or provide goods and services, but also the staff system which serves the operational system. The same types of operational improvement are possible in functional areas outside of the traditional manufacturing area—for example, sales, R&D control, etc.
5. Design of control systems for these resources. The systems by which the planning, scheduling, or co-ordinating of resources is done represents an important area for company improvement and is a challenging design opportunity.
6. The evaluation of results achieved in the performance toward objectives, i.e. the realization from the investment in human, physical, or money resources as measured by the satisfaction of human and management wants. Such evaluation, though difficult, provides conclusions which when fed back close the loop described in 1-5 above. If the realization obtained is not satisfactory, the Industrial Engineer is asked to re-examine the organization, objectives, allocations, resources, use, control, and realization. This full circuit can be generally applied to any type of organized human activity—industry or government, etc.

In the above areas management is looking to an Industrial Engineer more and more as an individual who can step back far enough from the day-to-day operations to observe objectively the system by which the company is run rather than to the sharpness or the number of tools in his kit. Further, management looks to an Industrial Engineer to assist in interpreting what he has seen and experienced to the other people in the organization.

These paragraphs have summarized the dramatic change that has taken place in the profession. The scope and contribution of leading practitioners in the Industrial Engineering profession today are quite a contrast to the time study man or efficiency expert of the 20's.

## INDUSTRIAL ENGINEERING PROCESS CHART

As related, the Industrial Engineer performs many functions and interacts with management and the objectives of the organization he serves in many ways. The Industrial Engineer is part engineer, part research oriented, part an operating entity and often a salesman of systems. This combination of activities has been termed the industrial engineering "process" (3) and the chart shown is an attempt to depict the process for ease of discussion, Figure 1. It is intended to graphically illustrate the activities involved and to categorize the activities engaged in as operating, engineering, and/or research. The

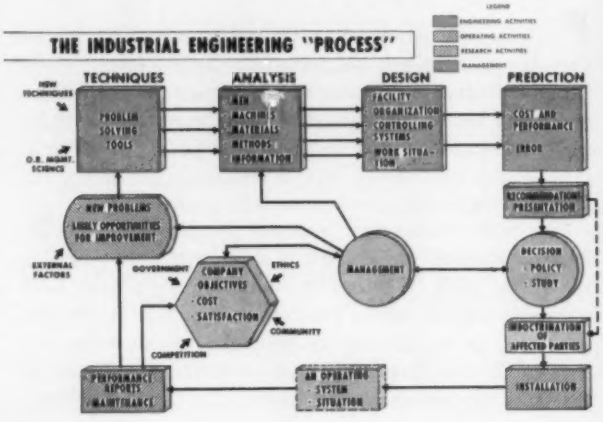



FIG. 1

boxes across the top represent the engineering activities in the Industrial Engineering process. The "technique" and the "design" boxes are two areas that will be discussed in the next section of this report. Across the bottom are the "operating" activities which have often comprised the Industrial Engineering Department in a company. As noted earlier, the trend is away from such narrow use of the term "Industrial Engineering" by management. Up the left side is illustrated the research activities, the refinement of existing techniques, the development of new, and the transfer of techniques from other branches of engineering, science, humanities, etc. The relation to management and the objectives of the organization are also noted. The symposium group endorsed the diagram as depicting the process by which change is engineered and controlled—i.e., the *Industrial Engineering Process.*

## TOOLS AND TECHNIQUES

Having identified the areas where the Industrial Engineer can operate effectively and the process he is implementing, discussion turned to outlining the tools and

techniques used in this work. The list of tools that the group felt important was quite extensive. The degree of knowledge and skill the Industrial Engineer should have in each of these areas proved impossible to treat satisfactorily and is scheduled for discussion at the next symposium. The levels of knowledge extend from expert or comprehensive to elementary, i.e. enough to recognize a need and to know where to find expert advice. However, there was agreement that the Industrial Engineer serves as the unifying force in bringing together the knowledge and talents of the various scientific and engineering disciplines, and in integrating them into a cohesive team to assist management.

Since the Industrial Engineer is concerned with the design, improvement and installation of systems involving men, materials, and equipment he must have fundamental training in mathematics, physics, chemistry, and in the engineering sciences. The treatment of the human component of the system requires knowledge of the behavior, motivation, capabilities, and limitations of people. Knowledge derived from training in the social sciences, as psychology and sociology, is necessary to predict and describe the variations in the performance of men, equipment and processes and the environmental factors affecting them. The Industrial Engineer makes extensive use of probability and mathematical statistics. A wide variety of special tools and techniques are used in the analysis and design of complex integrated systems. Among these are methods of linear and dynamic programming, gaming theory, digital and analog simulation systems, control theory, computer applications, etc., and such tools as process charts, methods analysis, etc. Knowledge of proper experimental methods in dealing with experimental situations is also required.

The evaluation of both systems and components requires familiarity with the various branches of economics, including econometrics, the economy of the firm and engineering economy and with the techniques of modern decision theory. Typical tools used in setting standards for and in measuring the performance of men, equipment, and systems range from work sampling, micromotion and time study to synthetic time standards. Working closely with management the Industrial Engineer must be familiar with management principles and organization theory. He must have the experience, skills, and knowledge necessary to design, analyze, and evaluate management control systems for cost, production, and quality. Because he deals with people at every level of the organization and because his work directly affects the activities of these people, the Industrial Engineer must have the special skills necessary to convey his ideas and results by verbal, written and visual methods. This problem of efficient communication is becoming more important as our requirement for more frequent change increases.

How does an Industrial Engineer use these tools and techniques when he first contacts the reality of the problem area? In the initial or *survey phase* he utilizes visual observation and preliminary data samples to design subsequent approaches and determine the scope of his analysis. He would include a review of records that are available for an existing activity, a check for similarities to existing activities if a new design, and a certain amount of elementary variance analysis as well as elementary sensitivity or correlation analysis. From these he would begin to develop a conceptual model of the area under investigation and to comprehend directions in which improvements may be made. The whole process of design through which the Industrial Engineer may subsequently go is carried out in a rough conceptual way in this first approach.

Next the Industrial Engineer must usually design a method of *obtaining additional information*. Normally, this will require the selection of suitable units of measure and the design of data collection or experimental statistics to design such procedures.

The third phase is *modeling*; putting measurements into a form representing some important aspects of the situation. Many of the tools and techniques are useful in this phase: job standards, process charts, flow diagrams, layout models, or simulation programs.

What techniques are available for *manipulating the model* that has been constructed? The simplest manipulative activities are those which the Industrial Engineer recognizes in the "why" approach of work simplification, as used on a job description, process flow chart, or plant layout. For other models, appropriate manipulations are chosen: for example, Monte Carlo methods in process simulation. In addition to the manipulative techniques, the Industrial Engineer uses his creative imagination and experience, seeing relationships, patterns, new potential, and introducing knowledge from other fields.

These phases are part of a repetitious cyclical process which may be repeated several times to evolve a design which meets the final design criteria, and which may also be analyzed by critical processes or decisions of management. These same models can ultimately be used for performance evaluation, derivation of reports, and as a base for the payment of incentives.

## FUTURE PLANS

As mentioned, the Sixth Symposium will be devoted to exploring the degree of knowledge the Industrial Engineer should have in each of the many tools and techniques available to him for use in his work. In addition, the relation of the Industrial Engineering process to the management process, partially suggested in the process chart, will be explored in detail. The question of what is Industrial Engineering versus what is management should provide an interesting session at Northwestern University this fall.

## LIST OF PARTICIPANTS

**Mr. W. E. Alberts**
Vice President Industrial Engineering
United Air Lines
Chicago, Illinois

**Dr. Lee S. Christie**
System Development Corporation
Santa Monica, California

**Mr. L. R. Cook**
Assistant Vice President, Engineering
Western Electric Corporation
New York, New York

**Dr. H. O Davidson**
Professor, Industrial Engineering
Georgia Institute of Technology
Atlanta, Georgia

**Professor J. W. Deegan**
Industrial & Management Engineering
State University of Iowa
Iowa City, Iowa

**Mr. T. Blair Evans,** Deputy Chief
Industrial Engineering Division
Directorate, Maintenance Engineering
Air Material Command—USAF
Wright-Patterson Air Force Base, Ohio

**Mr. G. R. Ewing**
Chief Industrial Engineer
R. R. Donnelley & Sons
Chicago, Illinois

**Mr. R. A. Forberg**
Director, Industrial Engineering
Division, Procter and Gamble Company
Cincinnati, Ohio

**Dr. W. R. Hudson**
Associate Professor of Industrial and Management Engineering
State University of Iowa
Iowa City, Iowa

**Dr. R. N. Lehrer**
Chairman, Industrial Engineering Department
Northwestern University
Evanston, Illinois

**Mr. D. G. Malcolm**
Director, Operations & Management Research
System Development Corporation
Santa Monica, California

**Mr. Morley H. Mathewson**
Director Industrial Engineering Department
International Minerals & Chemical Corporation,
Skokie, Illinois

**Dr. L. G. Mitten**
Professor, Industrial Engineering
Northwestern University
Evanston, Illinois

**Mr. L. T. Ohmart**
Director of Industrial Engineering
Mack Trucks, Inc.
Allentown, Pennsylvania

**Dr. A. W. Rathe**
Professor, Industrial & Management Engineering
New York University
New York, New York

**Mr. Robert J. Rohr, Jr.**
Assistant Director of Industrial Engineering
Kodak Park Works
Eastman Kodak Company
Rochester, New York

**Dr. Andrew Schultz,** Head
Department of Industrial & Engineering Administration
Cornell University
Ithaca, New York

**Mr. John R. Shelton**
Chief Operations, Standards Division
Port of New York Authority
New York, New York

**Mr. F. J. Titler,** Executive Secretary
AIIE Headquarters, 145 North High Street
Columbus 15, Ohio

**Mr. Austin Weston**
Manager Engineering Department
Western Printing & Lithographing Company
Racine, Wisconsin

## REFERENCES


(1) "Summary of the Industrial Engineering Symposium, Cornell University, October 1955," Austin Weston, *Journal of Industrial Engineering,* May-June 1956.

(2) "Summary of the Industrial Engineering Symposium, Purdue University, November 1956," Austin Weston, *Journal of Industrial Engineering,* March-April 1957.

(3) "The New Industrial Engineering," D. G. Malcolm, *Journal of Industrial Engineering,* November-December 1956.



*Available*

**PROCEEDINGS OF THE TENTH ANNUAL NATIONAL CONFERENCE OF THE AMERICAN INSTITUTE OF INDUSTRIAL ENGINEERS**

**Held May 14, 15 and 16**
**Biltmore Hotel, Atlanta, Georgia**

| | |
|---|---|
| **AIIE Members** | **$5.00** |
| **Non-Members** | **$7.00** |

**Orders should be directed and checks made payable to Tenth National Conference, P.O. Box 5255, Station E, Atlanta 7, Georgia**

# Institute Interests

## PROFESSIONAL RELATIONS ACTIVITIES

### *A Progress Report of Professional Relations Activities for the Year 1958-1959*

All of us can note with considerable pride the resolute manner in which Industrial Engineers have participated in many activities which aim at solving, with the other Engineering Societies, problems that confront our profession as a whole. We are still a relatively small group in number, but quality has not been wanting in our ranks and has more than made up for lack of quantity. A review of the activities carried on by our Professional Relations Committee during the past year under the skillful guidance of Dr. Alex Rathe is another instance of the maturity that we have attained in the eleven years of our existence.

This Committee, which is only four years old, undertook the astonishing total of thirty-eight projects during the past year, which is just about double the total number worked on during the preceding year. A total of one hundred-twenty members of AIIE—many of them representing the top talent of this country—participated in these projects. The organization and administration of such a large force scattered over most of the United States is in itself an accomplishment reflecting the high degree of managerial skill that is available within the top ranks of the AIIE.

These thirty-eight projects fell into two categories:

1. A total of thirty represent AIIE participation on problems of national impact which are jointly undertaken by organizations representing a number of major fields of engineering specialties. These have been primarily:
   a. United Engineering Trustees.
   b. The Engineers Council for Professional Development.
   c. Engineers Joint Council.
   d. Engineering Management Conferences.
2. The remaining eight projects are within the Institute itself.

### *Joint Projects With Other Engineering Groups*

*United Engineering Trustees*

By far the most ambitious of all projects is the Institute's plan to move the national office into the new $10,000,000 United Engineering Center. As few years back as 1954, all AIIE members would have cheered such a possibility; but realistic men would have had to dismiss it as day-dreaming. Today, five short years later, this vision is becoming a reality—thanks to the untiring efforts of all chapters.

The Center whose combination of attractiveness and efficiency will stand as a mighty monument to the entire engineering profession, is being erected as the new home for the major engineering societies. Plans for its completion visualize occupancy in 1961.

For an organization like AIIE which is relatively young, such surroundings will represent an improvement far in excess of that which awaits the older societies. AIIE members will have access to the most extensive engineering library in the world; our national headquarters will be able to provide even better and faster service through availability of the most modern office (duplicating, data processing, mailing, etc.) equipment; meeting rooms will be available to Institute committees, etc.

The very layout of our national office—high up in one of Manhattan's most distinctive skyscrapers, with a view from the Statue of Liberty to the United Nations—will represent impressive evidence of the share which Industrial Engineering has had in the technological developments of our times.

Negotiations are proceeding which will crystallize, in appropriate legal language, our long range right to occupancy as well as a voice in the management of the new building.

*Engineers Council for Professional Development*

The second and third of the joint projects fall within the province of ECPD. Eight major engineering societies have combined their efforts within this organization on behalf of problems within the profession itself. Ethics, education, professional development of the young practitioner are among the key activities. Although ECPD has not been accepting new members for a number of years, AIIE has been invited to participate in two of the most important areas of its work, namely:

1. The ECPD Training Committee: Here programs are being designed for the further development of the young graduate; in 1958-1959, the AIIE delegate has been given the task of preparing a manual for implementation of this objective on the local level.
2. The ECPD Accreditation Committee: This group guides Inspectors of Engineering Curricula; AIIE's Education Committee has the task of drafting a list of nominations of competent men for this task; the Professional Relations Committee maintains liaison with ECPD on this matter.

*Engineers Joint Council*

With twenty organizations on its membership rolls, EJC societies represent over 300,000, i.e. something like one-half of all engineers in this country. This is an increase of 15% in one year.

AIIE, one of the ten constituent members of EJC since 1958, is active in all major fields which this largest of all engineering organizations covers. Our delegates have participated in a total of twenty-six different projects during the year 1958-1959, including the two top governing bodies of EJC, namely its Board of Directors and (since January, 1959) the EJC Executive Committee.

The single most significant development during this period has been the unanimous stand by EJC Directors in favor of an amalgamation of the activities of EJC and ECPD. Its realization would bring us a big step closer to the time when one group can speak for all of the professional engineers in the United States, without regard to technical specialties.

Among the total of 26 EJC projects in which AIIE participated during the past twelve months, are:

1. Surveys on demand for engineers, their salaries and working conditions.
2. Recommendations on engineering manpower utilization in defense contracts. This report has attracted wide following within EJC and beyond; for instance, the Scientific Manpower Commission has specifically requested to be permitted to endorse the recommendations. The work has been done under the chairmanship of Mr. Herbert Ashcroft (then Chief Delegate to the Engineering Manpower Commission), in cooperation with the other AIIE Delegates, namely Messrs. C. H. Doolittle, N. Olijnek, L. Holmes and G. Kleis. The opinion has already been voiced that this particular report will take its place with other EJC recommendations which attracted particular nation-wide attention, such as EJC's proposals concerning economic rebuilding of Japan and Germany after the war, its proposal on a National Water

Policy on Air Pollution, etc. It is work of this calibre which has contributed so much in recent months to the increasing recognition which AIIE is enjoying within EJC and other circles.

3. The first Regional EJC Meeting was held in Chicago in June, 1958. It dealt with the "Next Decade in Engineering" and was arranged by the EJC Program Committee whose chairman was the AIIE Delegate.
4. The start of an authoritative study on the economical and social implications of Automation (currently chaired by the AIIE Delegate).
5. Development of a program which would make the member benefits of one EJC Society available to members of other EJC Societies.
6. Cooperation with the National Science Foundation.
7. Study of the impact on the profession if the Federal Government were to establish a Department of Science and Technology.

There were many other projects. For the first time in its history, Industrial Engineering was represented in the deliberations of the Presidents of all major engineering Societies. Three such meetings were held during 1958-1959.

*Engineering Management Conferences*

Once a year, the most prominent among all engineers and managers come together to discuss problems of managing engineering working in a two-day Conference. This event originated with ASME which invited the other four Founder Societies and AIIE to co-sponsorship.

In participating for the first time in the preparation for the 1959 (Los Angeles) Conference, AIIE's view was accepted, namely that Engineering Management represents an area of joint interest to all branches of the profession while Management Engineering remains the concern of the Institute.

The major portion of the work for the Los Angeles sessions has been done by ASME, AIEE, and AIIE; but the feeling of cooperation is such that this activity will ultimately form strong professional bonds between the participating societies.

Registration fees for these Conferences are set on the strength of a budget which aims at breaking even (at member rates). Attendance in the seven years during which the Conference has been run, varied between roughly 200 and 400. In every case, arrangements were made so as to make the event self supporting.

At present, ASME and AIEE jointly share the responsibility for financing. AIIE and the other societies have been invited to participate in this in the the future. Mr. E. H. MacNiece (Technical Consultant, Permacel, Inc., New Brunswick), our chief delegate to these events, recommends that: AIIE will, starting with the 1960 Conference, share with the other Societies financial responsibility for each event. There is no reason to assume that the Conferences of the future should suddenly run in the red; if one should, however, a proportionate share of the loss would have to be assumed by AIIE.

***Projects Within AIIE***

*Task Force on Criteria of Cooperation with Other Societies*

This group has a dual objective:

1. It aims at facilitating further joint efforts with other engineering, scientific and management groups by pinpointing the sectors of major concern for the Industrial Engineer.
2. It seeks to safeguard against dilution of Institute efforts.

During 1958, the Task Force was chaired by Dr. M. D. Kilbridge. Unexpected developments made it, much to the regret of everyone, impossible for him to continue in this capacity. Mr. Marvin Claeys (Quality Control Superintendent, United Air Lines, Chicago, and past president of the Chicago Chapter) has just taken over the reins of this group whose work will continue during 1959-1960. Dr. Kilbridge will remain a member of the Task Force, together with M. E. Gibian and Dr. M. Lohmann.

*Task Force on Unity*

No profession in the United States counts nearly as many practitioners within its ranks as Engineering. Yet our field still lacks the counterpart to the American Bar or the American Medical Association, which can speak for all members of their respective profession without regard to specialty training or interest.

For many years, men of good will from many quarters have attempted to bring about greater unity within Engineering. As a result, there exists a number of plans to make this high goal a reality—either in the form of unified organization or, at least, through a program which could be supported by several or all of the key organizations.

Of course the very existence of EJC and the effectiveness of its operations constitute a major achievement in this direction. But a lot remains to be done.

Composed of some of Industrial Engineering's most prominent men, this Task Force has as its objectives the formulation of the Institute's possible contributions toward that end. Included in its scope are consideration of:

1. The Institute's relations with EJC.
2. The possible amalgamation of EJC and ECPD.
3. The so-called "Functional Plan" (very actively propagated by its author, AIEE) and blueprints developed by other constituent societies, all aiming at coordinating or merging operations currently carried on by several organizations.
4. The role of NSPE.

As an interim guide, the Task Force presented to the AIIE Board of Trustees the following policy:

1. AIIE should not be the leader on unity at EJC.
2. AIIE considers as its minimum position on unity the support of a merger of EJC and ECPD activities.

This proposal was unanimously adopted at the October, 1958 AIIE Board Meeting.

How timely this action was, is probably best shown by the fact that the January 6, 1959, meeting of the EJC Board of Directors and the February 3, 1959, meeting of the ECPD Executive Committee unanimously adopted one specific proposal directed at the amalgamation of EJC and ECPD operations. It is now in the process of action by the governing bodies of all EJC and ECPD societies.

The AIIE Board, on the strength of recommendations by this Task Force, unanimously voted in favor of the principles of this proposal as a first step toward unity efforts. At the present time, Task Force deliberations on further steps are in abeyance pending the reaction which this proposal will have in the Board sessions of the other societies. Past-President Gustat has assumed the chairmanship of this Task Force.

*Task Force on Industrial Engineering Classification in Civil Service*

The objective of the undertaking is to assist the Federal Government in setting up a system for proper categorization and compensation of Industrial Engineering occupations. Work started only recently, under the chairmanship of Mr. Wm. K. Hodson. It is scheduled for completion by December 31, 1959.

*Task Force on Professional Standards*

With the gracious and most active cooperation of Dr. L. Gilbreth, this group studied the desirability of standards with regard to:

Professional ethics.
Functions of the Industrial Engineer.
Education.
Membership qualifications.

The Task Force included: Dr. Lillian M. Gilbreth, Mr. Harry L. Davis, Mr. Frank M. Gryna, Jr., Mr. S. Gerald Isley, and Mr. Harold M. Scherr, Chairman. The report of this Task Force has been submitted to the Board of Trustees for decision on appropriate action.

*Task Force on Professional Development*

This is the second group which completed its work during the current year. It is composed of Mr. Richard A. Forberg, chairman, and Mr. Warren E. Alberts.

The Professional Relations Committee activated this Task Force last year because of numerous requests from Chapters for information and assistance in projects aiming at further professional development of the Industrial Engineer.

The result of the studies by this Task Force is a blueprint for action at the national level as well as for every Chapter which desires to avail itself of the program. The pioneer efforts of ECPD in this field are the bases for the Task Force recommendations.

*Task Force on Synchronizing Professional Relations with Other Institute Activities*

Many AIIE activities have a direct, often a critical, impact on our relations with other parts of the engineering, scientific and management worlds. To prevent several components of AIIE from working at cross purposes, the Professional Relations Committee created this Task Force last year, with the explicit approval of this objective by the Board. Its responsibilities cover action on the national as well as regional and local levels.

Under the chairmanship of Mr. Floyd J. Titler and ably assisted by Mr. J. L. Southern and Dr. Andrew Schultz, Jr., the group has developed several steps and procedures which make a start toward assuring this result on the national level.

*Information Services Group*

A group was organized to issue a Professional Relations News Letter about once every three weeks to all members of the Professional Relations Committee, all chapter presidents and national officers. A bi-weekly Newsletter that reaches all chapters is *also* being prepared and distributed by this group in connection with the present United Engineering Center Campaign.

***What Lies Ahead?***

AIIE has entrusted the Professional Relations Committee with responsibility for more and better cooperation in the three orbits which Industrial Engineering intersects, namely: the engineering world, science, and management.

Most appropriately, the main emphasis in the first four years has been on cementing our relations with other engineers. At this time, these are as firmly established within EJC as the most optimistic hopes would possibly desire. Our bonds with ECPD and NSPE are less strong.

Consequently, this committee will devote special attention to these areas in the future. Former Board action has already given the Committee the formal authority and the flexibility needed to deal effectively with as yet unforeseeable developments.

In addition, cooperation with scientific and with management organizations has to be strengthened. The results of the Task Force on Criteria of Cooperation are likely to provide the basis for future action once the Board has acted upon them.

Dr. A. Rathe concluded his report to President George Gustat with the following words which I have taken the liberty to quote in full: . . . "These pages indeed reflect progress. It is due to the 120 men and women who have been active on the 38 projects during the past 12 months. They have represented the professional interests of our members with such skill and vision that all of us can today fulfill our obligations in our careers better because we are strengthened by the ever-wider recognition of our chosen field of Industrial Engineering."

*Reported for the Professional Relations Committee*
*By* O. J. FEORENE

**CALENDAR**

September 21-25: Fourteenth Annual ISA Instrument-Automation Conference and Exhibit, International Amphitheater, Chicago, Illinois; sponsored by Instrument Society of America. Write: H. S. Kindler, Director of Technical and Educational Services, ISA, 313 Sixth Avenue, Pittsburgh 22, Pennsylvania.

**MIDWEST REGIONAL CONFERENCE**

The 1959 Midwest Regional Conference of AIIE was held on Thursday and Friday, April 2 and 3, at the Furniture Club on the 17th floor of the American Furniture Mart Building, 666 North Lake Shore Drive, Chicago, Illinois. The entire program for this conference was selected, organized, and developed around the idea of improving the individual's effectiveness, whether in the design and improvement of management techniques, or the installation and administration of them.

The keynote address was given by Mr. Lee S. Whitson, AIIE Vice President of the Midwest Region. Mr. Whitson's present position is Vice President of Manufacturing, Toro Manufacturing Company.

An analysis of two major internal methods of increasing company profits constituted one of Thursday's three concurrent sessions. H. Barrett Rogers led the analysis of "Financial Incentives," while Edmond A. Cyrol presented "Blueprints For Cost Reduction."

Another of Thursday's concurrent sessions consisted of two seminars on specific vocational areas. A speaker discussed the subject from a general point of view, establishing the seminar foundation; then a panel presented specific practical subject applications. Then followed a question and answer period.

The I. E. Seminar was introduced by Dr. William Gomberg who developed the title "Industrial Engineering—Past, Present and Future," exploring the trends in specific areas. This was an objective treatment of the history and status of Industrial Engineering, and a professional prediction of the field's future.

The Management Seminar was introduced by Mr. George A. Hoy, Jr., who based his presentation on "Managed Motivation"—a consideration of human motivation and management principles, and the "will-to-work" state of affairs. Mr. Hoy holds the position of Industrial Management Editor of *Factory Management and Maintenance* Magazine.

Speakers on Friday included: David B. Klapper, currently engaged in operations research for Commonwealth Edison, who spoke on the "Digital Computer Problem Solution"; B. G. Gross, who is Industrial Relations Director for the Chicago-Isham Memorial Y.M.C.A. as well as Executive Secretary of the Northtown Industrial Management Club, and Director of Personalysis Measurements Counsel, treated the subject of "I" Improvement. R. Dystant, a partner of the organization offering stock market classes in the Chicago area, lectured on "Stock Investments." Floyd W. Simerson, Assistant to the Vice President in Charge of Factories, Sears, Roebuck & Co., spoke to the conference on "Work Simplification"; and Gordon White, Vice President and Copy Chief in the Chicago office of Batten, Barton Durstine & Osborn, Inc., one of the world's largest advertising agencies, dealt with the subject of "Cooperative Problem Solving."

**AKRON CHAPTER**

The Akron Chapter was honored to have as its April speaker nationally known industrialist and business leader, Mr. James F. Lincoln, Chairman of the Board of the Lincoln Electric Company. Mr. Lincoln's talk on "Incentive Management" was extremely well thought out and presented to our group.

Our May meeting, a Ladies' Night program, featured Miss Beth Peterson, a well recognized Home Economist. Miss Peterson, who works for the du Pont Company, discussed "The New American Look in Living."

At our June meeting, the topic of discussion was "How Can the Industrial Engineer Best Serve Management?" The following four vice presidents were our panel guest speakers: Mr. Samuel Du Pree of Goodyear Tire & Rubber Co., Mr. Joseph A. Meek of Firestone Tire & Rubber Co., Mr. Russell D. Rudolph of Diamond Crystal Salt Company, and Mr. Paul H. Setzler of the Babcock & Wilcox Company. Annual reports and elections rounded out the meeting.

**CHARLESTON-HUNTINGTON CHAPTER**

Although both Charleston and Huntington, West Virginia, are more than 200 miles from West Virginia University at Morgantown, the Charleston-Huntington Chapter has expanded its program of service to the AIIE Student Chapter there.

An award to the oustanding senior Industrial Engineering student has been established to create greater student incentive and provide recognition to the most deserving student. The first annual award was presented to John H. Laing of Lewisburg, West Virginia, by W. L. Emmert, Charleston-Huntington Chapter President, during the Industrial Engineering Conference held at the University on April 13 and 14. The selection of the outstanding senior was made by Professor R. E. Shafer and the Industrial Engineering faculty at the university and was based on scholastic achievement, character, and leadership criteria.

Another point in the program for closer association between the senior and student chapter has been the arrangements made for speakers to appear before student chapter meetings. On April 30, Mr. Pat Huff of the Union Carbide Chemicals Company, Charleston, West Virginia, spoke to the student chapter members on Industrial Engineering Applications in a Process Industry. The following month on May 14th, Mr. John Reevy of the International Nickel Company, Huntington, presented a short talk on Human Relations and the Industrial Engineer. Both Mr. Huff and Mr. Reevy are members of the Charleston-Huntington Chapter.

A greater program of student chapter aid is currently being planned by E. J. Bazel, Student Chapter Committee Chairman.

Charleston-Huntington Chapter members who took prominent part in the Annual Industrial Engineering Conference held at West Virginia University on April 13th and 14th were Professor R. E. Shafer, Charles G. Howard, John H. Meincer, and Charles Roundtree, Jr.

**ERIE CHAPTER**

The program for the 1958-59 season has been broad and extensive for the Erie Chapter of AIIE. Ralph W. Day, Manager of Industrial Engineering, Rockwell Manufacturing Company, was the kick off speaker. Erie's Mayor, Arthur Gardner, presented a timely talk on "Erie's Industrial Climate and What Effect the St. Lawrence Seaway Will Have on It." An interesting plant tour of the Bucyrus Erie Plant and a film session were followed by George Gustat, our national president, speaking at the February meeting on "The Use of Photography in Industrial Engineering." The latest in material handling equipment was well covered by Christian G. Kramer of the Yale and Towne Mfg. Co. The second annual "Meadville Day" took place April 15th as the members from the Meadville, Pennsylvania area invited the Ericites to travel to Meadville for a dinner meeting. The speaker for the evening was Cleveland C. Judd, Personnel Director of Talon, Inc., who spoke on the topic of "Management Development." The program chairman rounded out the season with a tour of a local brewery.

The chapter's public service committee was able to complete two projects this season at the Sarah Reed Home, a non-profit organization caring for needy children and adults. The first study was a boiler efficiency study to determine whether it would be economical to convert from coal to gas. This survey was performed jointly with the ASME and resulted in the recommendation to retain coal. P. J. Murray and D. H. Infield were the contributing consultants from the AIIE chapter. The other study conducted by D. H. Infield, R. G. Cooper, R. R. Phillips, and E. G. Volpe, was an appraisal of the laundry. The Home was considering farming out the laundry to a commercial laundry. By suggesting several methods improvements, the committee was able to recommend retention of the Home's laundry.

Thirteen local chapters of various engineering societies are now represented in the Erie Engineering Societies Council. The AIIE is well represented on committees, and as officers; P. J. Murray has been elected Vice President, and R. M. Soth as Treasurer for the next term. This group is sponsoring a Science Scout troop, is reviewing all text books in the local school district to evaluate their scientific content for accurate and up-to-date information, has presented talks to local high school students on the subject of "Engineering as a Profession," is publishing a monthly journal on engineering activities, and sponsored an Erie Engineering-Management conference held April 22, 1959.

The membership of the Erie chapter of AIIE has reached forty-six with enough prospective members to break fifty by next season.

**LOUISVILLE CHAPTER**

Mr. Keith Boaz, Staff Engineer for Institute of Modern Management, was the guest speaker for the March meeting which was held at the University Center Cafeteria on the University of Louisville campus. His presentation was another in a series of meetings concerning Indirect Labor. Mr. Boaz pointed out some areas in the Indirect Field that are presently being examined for improvement in cost recovery. Mr. Howard Morris, Manager of the Methods and Standards Department at Tube Turns, Inc, also took part in the program by explaining the work mechanism of the "Truck-O-Meter."

Our April meeting featured Mr. Norman K. Morrison, Product Manager of Executone, Inc., in New York, as guest speaker. Mr. Morrison's subject of "Centralized Timekeeping" proved to be of great interest to all those members who attended the meeting.

**METROPOLITAN NEW JERSEY CHAPTER**

Dr. Adam Abruzzi, Professor in the Department of Economics of Engineering, Stevens Institute of Technology, was guest speaker at the April 23rd meeting of the Metropolitan New Jersey Chapter. His presentation on "Work Measurement" explored in depth thought-provoking questions relative to labor management relationships in the area of work standards and incentives in the United States and other countries.

By the qualitative application of game theory, Dr. Abruzzi made clear the effect of the bargaining process on the establishment of work standards and the limitations on their scientific determination.

**MIDDLE TENNESSEE CHAPTER**

Mr. J. M. Wild, Director of Engineering for ARO, Inc., was the guest speaker at a joint meeting of the Middle Tennessee and the Chattanooga Chapters of the American Institute of Industrial Engineers held Thursday Night, April 9, at Monteagle Diner.

Mr. Wild was introduced by Mr. Ernest Teasley, President of the Middle Tennessee Chapter.

Mr. Wild presented a very enlightening, informative and challenging talk to the group on "The Future of the Engineer." He pointed out the tremendous progress man has made in the past 150 years and the increasing growth in the number of engineers during this time. The future of the engineer is unlimited when you

compare how much man knows with how much he does not know. He then pointed out that the engineer must accept the challenge and responsibility he has to his fellow man in the coming years.

## NORTHEAST FLORIDA CHAPTER

The Chapter was reorganized in October, 1958, to serve a greater number of I.E.'s in this area. The Chapter area now extends south to include Orlando, north to the Georgia border, and west to Tallahassee.

The first meeting after reorganization was held in Jacksonville in October, with an outstanding talk by Frank Johnson, National First Vice President of AIIE. His topic was, "Producibility Analysis—A Challenge to the I.E."

The second meeting, on December 5, was on the University of Florida campus in Gainsville, where arrangements had been made by the I.E. Faculty to play the U.C.L.A. Management Game using the IBM 650 computer at the University Statistical Laboratory. Briefing on the play of the Management Game was by Carlis Taylor, Supervisor of the Statistical Laboratory. Aside from playing the game and gaining some idea of the type problems which may be handled by this particular machine, all attending were impressed with the University facilities available to state industry.

In January of this year, we met in Orlando, where we had the largest turn-out in chapter history (80). This meeting was a triple feature, the first of which was a tour of the Martin Company missile plant. The second feature was a talk on "Work Simplification" by Carl Kromp, then Production Manager for Panelfab Co. of Miami and President of the Miami Chapter. He is now Head of Industrial Engineering at the University of Miami. Final feature was a drive to stir up interest in forming a Central Florida chapter in the Orlando-Cocoa, Cape Canaveral area. James Staples, I.E. Supervisor with the Martin Company in Orlando, was elected chairman of the Organization Committee.

On March 2, a meeting was held with the Student Chapter of the University of Florida as hosts. The speaker was Mr. John Feltman, Manager, Electronic Communications, Inc., of St. Petersburg, Fla., who spoke on "Why, When and Which Predetermined Time Value Technique."

On March 27 we met again in Jacksonville. Our original speaker, Lynn Bryan of Rock Island Arsenal, was snowbound. In the emergency Dr. Robert J. Wimmert of the I.E. Department at the University of Florida generously consented to fill in on less than five hours' notice. He did an excellent job of leading the group through the solution of a distribution problem using linear programming. Everyone participated by use of individual workbooks and visual aids prepared and duplicated by Dr. Wimmert within the limited time available for his preparation.

Our April meeting continued our policy of rotating the meeting sites to various cities with the large chapter area. The meeting was held in Palatka and included a trip through the Hudson Pulp and Paper Co. plant. The University of Florida Student Chapter were dinner guests of our chapter at the April meeting.

## STUDENT CHAPTER, OKLAHOMA STATE UNIVERSITY

The student chapter of AIIE at Oklahoma State University was the host for a joint meeting of the senior chapters of AIIE from Tulsa, Oklahoma City and Wichita on March 11, 1959.

The meeting was preceded by a banquet which gave the various members of the groups an opportunity to renew old acquaintances and the student Industrial Engineers a chance to meet some of the outstanding men working in the field in the local area. The banquet was presided over by the President of the student chapter, Ellis Kirks, who introduced the Presidents of the senior chapters: Mr. Terry Leard, Mr. Harold Colvard and Mr. Kersey Reed from Oklahoma City, Tulsa, and Wichita, respectively. The principal entertainment for the banquet was provided in the form of a film on Professional Engineering which was presented by Mr. Don Andrews of Oklahoma City.

TULSA AIIE PRESIDENT HAROLD COLVARD PRESENTING THE OUTSTANDING I.E. AWARD TO FOREST CAMPBELL.

The banquet was followed by a business meeting and an address by Dr. Clark A. Dunn, Oklahoma State University, who is national President of the National Society of Professional Engineers. Dr. Dunn discussed the various aspects of professional engineering as applied to the student and the engineer working in the field.

Another highlight of the meeting was the presentation of an award to Alpha Pi Mu for the outstanding chapter in the nation. Mr. Harold Colvard, President of the Tulsa Chapter, made their annual presentation to Forrest Campbell as the outstanding Industrial Engineering student for the year. This award consists of a handsome plaque and a check for the dues for the first year of membership in the American Institute of Industrial Engineers.

The meeting was concluded with an informal discussion of the activities of the various chapters.

## PITTSBURGH CHAPTER

At the April meeting of the Pittsburgh Chapter of AIIE, Jacob J. Blair, Professor of Industry at the University of Pittsburgh, gave a most enlightening talk on the subject of Arbitration. The specific title of his speech was, "Mr. Industrial Engineer, Are You Prepared for Arbitration?" Professor Blair was outstandingly equipped for this discussion for he was a Staff Arbitrator in the Conciliation Service, U. S. Department of Labor, from 1942 to 1946, and has been a practicing Arbitrator since that time. In 1953 he was appointed Vice President and Regional Chairman, National Academy of Arbitrators.

The Pittsburgh Chapter offered a most successful workshop seminar on Linear Programming on Monday evenings for six weeks beginning the 6th of April. This seminar, conducted at the University of Pittsburgh, was supervised by Dr. Albert G. Holzman. Dr. Holzman is presently Professor of Industrial Engineering at the University of Pittsburgh and has conducted the Industrial Management sessions at the University of Pittsburgh for top-level executives from throughout the world. The seminar was designed so that at least half of each session was devoted to the actual solutions of some practical problems which were directly applied by those attending. The only prerequisite was a basic knowledge of mathematics.

### ST. LOUIS CHAPTER

The April meeting of the St. Louis chapter of AIIE was indeed special, for this was our annual Students' Night Meeting. It took the form of a Plant Tour, buffet supper, meeting, and social hour, all at the Anheuser-Busch Brewery. Students from Washington University, under the leadership of Robert Yanick, their AIIE student chapter president, presented an interesting and thought-provoking program. A panel consisting of four speakers discussed the various angles of present-day educational problems in Industrial Engineering. In addition to students from Washington University, this year for the first time we played host to the student chapter from the University of Missouri. Some forty students from Columbia attended.

### WINSTON-SALEM CHAPTER

Mr. Norman J. Buddine spoke on the subject, "The Professional Engineer," at the January chapter meeting. Mr. Buddine has served as Chief Engineer for the R. J. Reynolds Tobacco Company for approximately eight years. Prior to this time he spent some years with the Stone and Webster Engineering Corp. of Boston, Mass.

The February meeting featured Dr. Clifton A. Anderson, Head of the Industrial Engineering Department at North Carolina State College. His talk was based on the theme, "The Industrial Engineer of the Future."

The Southeastern Regional Conference of AIIE was held March 18-20, 1959, at Winston-Salem. Engineers from seven states attended the three-day conference. Speakers were R. G. Newton of Stone and Webster Engineering Corp., W. J. Pettyjohn of the Westinghouse Electric Corp., R. H. Davies, executive vice president of Clark Equipment Co., Dr. B. G. Gross, author and counselor of Chicago, Illinois, and Dr. George K. Bennett, president of the Psychological Corp. of New York City. A panel discussion was moderated by Dr. D. J. Moffie, vice president of Hanes Hosiery Mills.

The conference was closed by Mr. Frank J. Johnson, manager of Production Engineering and Design Analysis for Lockheed Aircraft Corp. Mr. Johnson was named the outstanding engineer for the southeastern region.

# President's Message

FRANK J. JOHNSON
*President, American Institute of Industrial Engineers, Inc.*
1959-60

## Acceptance Speech as President of the American Institute of Industrial Engineers*

I APPRECIATE the great honor you have bestowed upon me by electing me President of the American Institute of Industrial Engineers for the coming year. I fully realize the task before me in trying to measure up to the accomplishments of George Gustat, Gordon Carson and the other capable men who have served as president. With all humility, I accept this challenge and with the cooperation and efforts of our vice presidents, directors and committee chairmen, we will continue to seek ways

* Presented: Biltmore Hotel, Atlanta, Georgia, Saturday, May 16, 1959.

to increase the recognition and prestige of the Industrial Engineering profession. With the help of dedicated men like Alex Rathe and his many committees, and, I might add, his sub-committees, every individual practitioner in our branch of the engineering profession will benefit from the growing prestige of our professional society.

Others such as Andy Schultz and his Research Committees will lead us into new fields of activity and service, helping us to grow professionally and to better qualify us to fulfill our prime responsibility, that of increasing productivity which is another way of saying "raise the American standard of living ever higher."

Let me commend to you your magazine, the *Journal of Industrial Engineering*, edited by the very capable, and hard-working Bob Lehrer. The men responsible for the magazine spend a great deal of time getting it out. If the AIIE members received no other benefits, this magazine alone would be worth more than the yearly dues.

Our dynamic growth is reflected in the fact that we have tripled in size during the past five years. For four consecutive years our rate of growth has been 24% per year. One might say that we were in a rut—an uphill type of rut. Thanks to Matt Payne's Chapter Expansion Committee, and to the hard-working vice presidents, we have added about 10-12 new chapters every year. The creation of a chapter in a community means better service to the individual member. We currently have about 500 members-at-large. This does not mean that they have escaped from custody but rather that they are unassigned to any chapter. Creation of new chapters helps to reduce this number of "members without an official home."

I believe that it is customary in acceptance speeches to set forth some type of "platform" upon which the incoming administration can set its goal.

My targets are very simple to state. Their accomplishment may be more difficult to attain, but with the capable people we now have, together with others whom we will draft to pitch in and help, I feel that one year from now in Dallas we can all be proud of a job "well done." This has always been the way with your previous administrations and we do not intend to impede that habit of success.

A breakdown of our objectives would show that our interest lies in the following areas—our profession, our Institute and the individual member and his chapter.

Development in these areas actually should be in reverse order to that just mentioned. We must first help the individual to grow and develop professionally. We will encourage each member to qualify himself as a Professional Engineer in those states that provide for registration of Industrial Engineers. We will continue our efforts for recognition in those few states that have not yet established registration laws. We will help the member by further improvement of our *Journal*. Our Institute will be in a better position to serve the members and chapters due to the re-organization of our regional set-up establishing ten regions to replace the six present regions. This change will allow our national officers to visit more chapters thus providing a communications link with national headquarters. This in itself will serve to keep minor irritations from festering into a major crisis.

In regards to your Institute and the operation of its affairs, we are this year facing major problems requiring thoughtful deliberation in order that we can solve them to the best advantage of all concerned. Perhaps the most important of these problems is the detailed planning required in connection with the move of our home office from Columbus, Ohio to New York City where we will be housed in the new United Engineering Center for which we are currently raising our share of the cost.

This study will require most of the tools of Industrial Engineering in order that we can solve problems of space layout, moving of staff personnel and/or training of new staff members. The logistics problems connected with a move of this kind are challenging to say the least.

Our able and hard-working headquarters staff will continue their efforts to constantly improve the service to the chapters and to the members.

Important as all these things are, perhaps the pressing need is to enlarge upon our efforts to increase the prestige of our profession. We have made great strides in the past few years as evidenced by our rapid acceptance into the hierarchy of outstanding organizations such as the Engineers Joint Council. The need for this recognition is evident. Other engineering organizations are in one way more fortunate than we are by virtue of their name being more descriptive of their function. The Electrical, Chemical and Mechanical Engineers have no problem in job identity. For example, the other day my 16-year-old son came home from school and told me that they had just had a "career day" program. He told me that he went to the meeting listing a speaker for Mechanical Engineering. When I asked him why he didn't go listen to the Industrial Engineer, he replied that he wanted something "specific." Therein lies our basic problem and the area in which we must expend more effort. We will continue our efforts in such fields as Research, Professional Relations and improvement of our already excellent *Journal*. We will create new committees and task forces, if necessary, to accomplish our objective—that of increasing the prestige and increasing the recognition of our Institute and profession. This Herculean task, of course, cannot be done by a few national officers and committees. It will require the constant awareness of all of us to "sell" Industrial Engineering at every opportunity. By "selling" I do not mean by the use of so-called "sales-pitches," but rather by the demonstration of each member—all 10,000 of us—in the day to day performance of our job, done in such a way as to reflect nothing but credit upon us and our profession.

All of this adds up to a big challenge, to me and my administration. With your help, and God's help, we will succeed!

# ie opportunities

## WHAT IT IS

The I.E. Opportunities service is a functional committee activity of the AIIE. Information concerning employment opportunities is collected on a nationwide basis and is provided without charge to members upon request. The committee is composed of members from the Columbus, Ohio chapter.

## SERVICES PROVIDED

Current job openings are published in condensed form in each issue.

In addition, a monthly I. E. Opportunities Bulletin is supplied to over seventy chapters located throughout the United States.

Each job opening is assigned a **"P"** number for identification. The name and address of the person to contact for additional information concerning a specific job opening is sent to members on request.

## EMPLOYERS

Employers having openings for qualified Industrial Engineers are invited to list them. Government agencies and educational institutions as well as business and industry are urged to take advantage of this free service.

Industrial Engineers are often employed in such fields as Work Measurement, Production Control, Plant Engineering, Operations Research, Industrial Relations, Sales, and Management. For a more complete coverage, see the following list of job classifications. Please do not hesitate to forward information on jobs in any area where it is recognized that an Industrial Engineering background will be of value.

To list your job openings with the Opportunities Service, send all or part of the following information with the name of your contact man to the address below: Type of industry, location, job classifications, minimum educational and experience qualifications, and salary range.

This information will be publicized to the members in condensed form in the JOURNAL and in monthly chapter Bulletins. Company names are not shown.

## MEMBERS SEEKING JOB OPPORTUNITIES

The following list shows job openings available just prior to press time. If you would like more information about one or more of the positions listed, mail the **"P"** numbers with your name and address to the Opportunities Service at the address below. The Service will advise you by return mail of the name and address of the person to contact for further information, or advise you if the position is no longer available. Your name will not be forwarded to the company with the job opening.

For more current listings, contact your local Chapter Secretary or Opportunities Chairman for the latest monthly Bulletin.

## ADDRESS OF THE SERVICE

I. E. OPPORTUNITIES SERVICE
American Institute of Industrial Engineers
145 North High Street
Columbus 15, Ohio

INDUSTRIAL ENGINEERING OPPORTUNITIES

| Position number | Industry, location | | Travel? | Job classification number (See key) | Salary | Qualifications required | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | Range in $1,000 | Adv. degree req.? | Years of exper. | Age range | |
| | | | | | | | | from | to |
| 17 | Air Force | O | | 11, 13, 31, 38, 42 | 8.8– | | 4½– | | |
| 41 | Consulting | O | × | 10, 21, 31 | | | 5–7 | | |
| 167 | Weapons Systems | Wash DC | | 50 | | Ph.D. | | | |
| 199 | Govt. Agency | Panama | | Engr. Trainee | 5.6–6.7 | | 0 | 20– | |
| 213 | Aircraft Rep. & Mod. | Cal | | 15, 32, 42, 43, 44, 53 | 7.5– | | 2½– | 21– | |
| 273 | Air Force | Utah | | 10 through 19 50–52 | 6.3–7.5 | I.E. degree | 2– | | |
| 308 | Automotive | Pa | | 19, 36, 38, 53 | 6.6–9.6 | | 4–6 | | |
| 316 | Mining | Nev | | 10, 20, 30, 40 | 6.0–9.5 | | | 21 | 45 |
| 317 | Mgmt. Consulting | NJ | | 10, 20, 31, 42, 54, 70 | 8.0–12.0 | | 5– | 30 | 45 |
| 321 | Steel | Ontario | | 10, 20, 38, 91 | 7.0–8.5 | | 5– | | |
| 323 | Steel | Ontario | | 50 | 5.4–8.5 | | 3–5 | | |
| 324 | Steel | Ontario | | 11, 13, 21, 22, 23 | 5.4–6.7 | | | | |
| 325 | Steel | Ontario | | 38, 53 | 5.4–6.7 | | | | |
| 328 | Research | Pa | | Human Engineering Res. | 6.0–9.0 | | 2– | | |
| 333 | Edu., Wood Prod. | NY | | 30, 37, 40 | | | | | |
| 334 | Education | Fla | | 10, 26, 31–36, 40–45, 53, 66 | | | | | |
| 339 | Automotive | Pa | | 11, 13, 15, 16, 22, 23, 36 | 6.6–9.6 | | 4–6 | | |
| 340 | Automotive | Pa | | 13, 14, 15, 16, 22 | 5.4–7.8 | | 0–2 | | |
| 341 | Printing | NY | | 10, 11, 22, 32, 42, 43, 21 | 7.8–9.5 | Graphic Arts Exp. | 3–5 | 24 | 35 |
| 346 | Education | Ga | | 19, 51, 53 | 7.0–10.0 | | 2–5 | 30 | 45 |
| 347 | Electronics | Ind | | 30, 32 | 7.2–9.4 | Electronic Asmby. Exp. Required | 3– | 25 | 45 |
| 352 | Air Force | O | | 50 | 5.7–12.5 | | | | |
| 362 | Aircraft | Conn | | 50, 51, 52 | Open | Milit. & Ind. Exp. | 1–4 | | |
| 366 | Graphic Arts | Ind | | 11, 13, 36, 42, 43, 70 | 5.8–8.0 | | 0–5 | 21 | 35 |
| 370 | Air Force | O | | | 8.8–10.0 | | 4½– | | |
| 373 | Education | Fla | | 31, 37, 38, 42, 50, 54, 71 | Open | M.S. Preferred | 2– | 25– | |
| 376 | Education | Mass | | | | | | 35– | |
| 377 | Electronics | NY | | 10, 30, 40, 70 | 4.5–7.5 | | 1–3 | 18 | 70 |

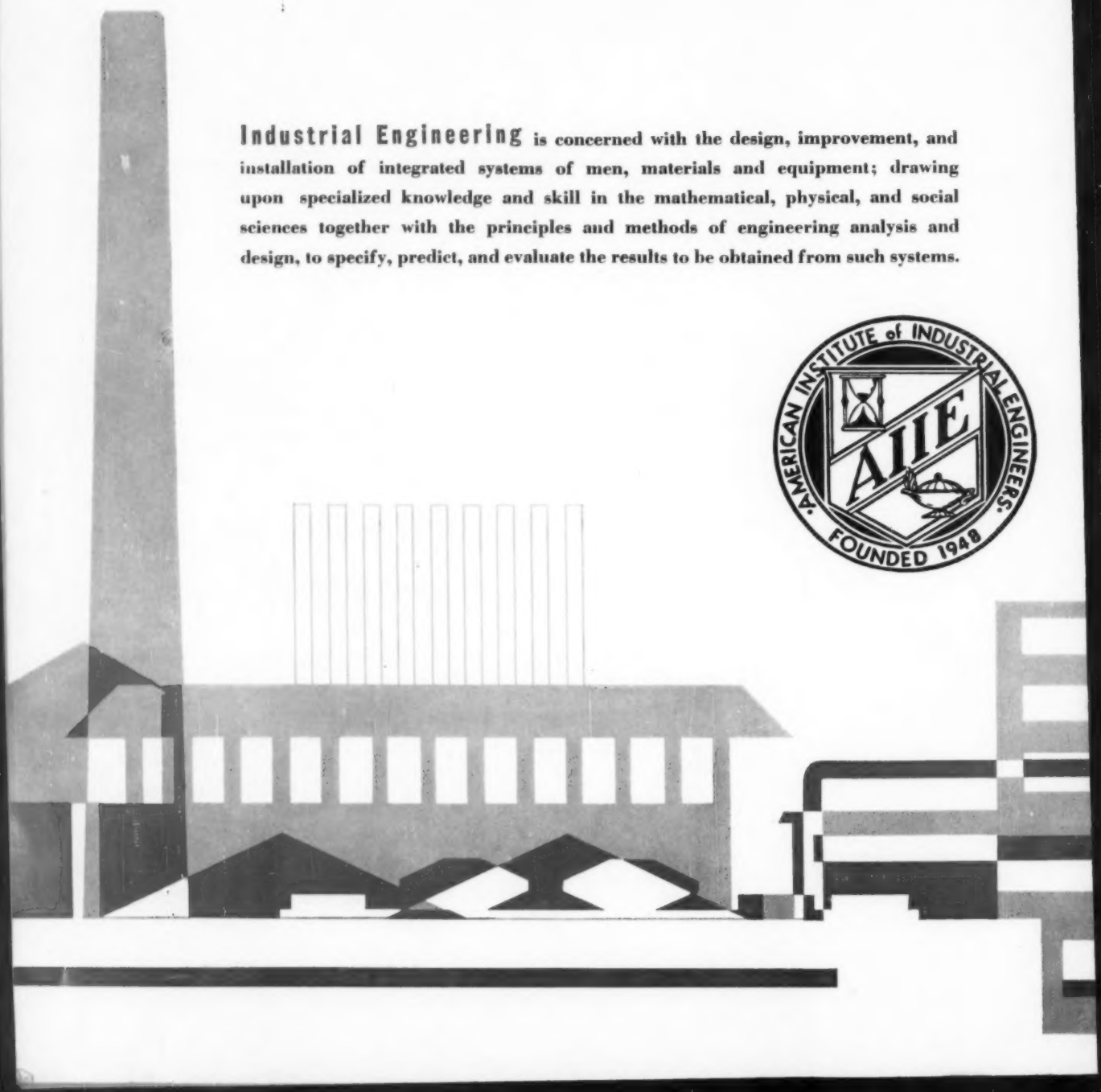
| Position number | Industry, location | | Travel? | Job classification number (See key) | Salary | Qualifications required | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | Range in $1,000 | Adv. degree req.? | Years of exper. | Age range | |
| | | | | | | | | from | to |
| 378 | Mgmt. Consulting | Ill. | × | Broad | 8.0–12.0 | | 5– | 28 | 40 |
| 385 | Carpet Mfg. | Va | | 10–28, 36, 42, 43, 44 | Open | I.E. Degree | 2–5 | 28 | 32 |
| 386 | Hospital | Ala | | 10, 30, 42, 53, 71, 72, 92 | 6.5–8.0 | I.E. Degree Reqd. | 3–5 | | |
| 395 | Soft Goods Mfg. | Tenn | | 10, 20, 30, 40, 70 | 7.5– | | 3–5 | 25 | 35 |
| 396 | Univ. | O | | 36–38 | 7.2–7.8 | | | | |
| 399 | Pulp & Paper | Ala | | 30, 40, 50 | | | 3–5 | 25 | 35 |
| 406 | Mfg.-Steel Goods | O | | 11, 36, 39, 41–48 | Open | I.E. Degree | 5–10 | 25 | 35 |
| 410 | Education | Tex | | Chairman, I.E. Dept. | | Industry Exp. | 10– | | |
| 412 | Mgmt. Consultant | Minn | × | 10, 30, 40, 70, 90 | Open | I.E. Degree | 5–10 | 30 | 40 |
| 414 | Printing | Wis | | 10, 11, 13, 15, 18 | 4.6–6.0 | | 0–3 | 21 | |
| 416 | Air Cond. Mfg. | Tex | | 10–19, 21, 26 | 8.0–9.0 | | 3–5 | 27 | 35 |
| 417 | Air Cond. Mfg. | Tex | | 10, 11, 21, 36 | 5.2–6.0 | | 0–2 | 23 | 30 |
| 419 | Food Processing | Ill | | 13, 15, 16, 38 | 5.7– | | 0–3 | | |
| 420 | Plumbing Supplies | O | | 11, 31, 32, 42, 43 | 7.2–9.6 | | 5–10 | 25 | 45 |
| 421 | Air Force | O | | 54, 70 | 11.3– | | 5– | | |
| 422 | Air Force | O | | 50, 52, 54 | 7.5–11.6 | | | | |
| 423 | Air Force | O | | Broad | 8.8 | | | | |
| 424 | Air Force | O | | Broad | 4.5–7.5 | | | | |
| 425 | Govt Agency | Wash, DC | × | 11, 13, 19, 33, 36, 48, 71 | 8.8–9.5 | | 4– | | |
| 426 | Mail Order | Minn | | 11, 18, 35, 36 | 6.0 | | 4–5 | 28 | 32 |
| 429 | Aircraft | Cal | | 19, 33, 34, 36, 38, 42, 43, 54, 71 | 6.2–10.0 | | 3–10 | | |
| 430 | Raylon, Nylon Mfg. | Tenn, NC | | 10–22, 26, 31, 33, 36, 42, 43, 50, 53, 67 | 6.0–8.0 | | 0–3 | Open | |
| 431 | Heavy Equip. | Ind | | 10, 11, 13, 14, 15, 16, 40 | 6.0–10.0 | | 2–10 | 27 | 40 |
| 432 | Aircraft-Missile | Cal | | 10–15 | 6.0–9.0 | | 3– | 25 | 45 |
| 433 | Synthetic Fibers | Fla | | 10, 11, 13, 18, 32–34, 43 | 6.0–8.0 | | 2–5 | 24 | 35 |
| 434 | Synthetic Fibers | Fla | | 10, 11, 13, 18, 32–34, 43 | 5.7–6.3 | | | 22 | 30 |
| 435 | Synthetic Fibers | Fla | | 11, 19, 33, 34, 43, 48, 53, 81 | 6.0–8.0 | | 2–5 | 24 | 35 |
| 436 | Education | Puerto Rico | | 37, 53 | 5.4–7.8 | | | | |
| 437 | Carpet Mfg. | Va | | 10–28, 36, 38, 42, 43 | 7.0–8.2 | | 3–5 | | |
| 438 | Electronic | Tex | | 81 | | Packaging Design Exp. | 3–5 | | |
| 439 | Electronic | Tex | | 36, 38 | | Acct. Degree & Exp. | 2–5 | | |
| 440 | Electronic | Tex | | 10, 11, 13 | | I.E. Degree | | | |
| 441 | Electronic | Tex | | 36, 38, 70 | | I.E. Degree-IBM 650 | 2–5 | 25 | 40 |
| 442 | Electronic | Tex | | 30, 31, 32, 33 | | Eng. Degree | | 25 | 35 |
| 443 | Education | Mont | | Broad | Open | Work on M.S. or Ph.D. | | | |
| 444 | Heavy Equip. | O | | 10, 15, 18, 21 | | | 4– | | |
| 445 | Dairy Prod. | Mass | | 10, 14–16, 42, 43 | 7.0– | I.E. Degree | 5– | | |
| 446 | Industrial Furnaces | O | | 19, 32, 35, 36, 38, 71, 95 | 6.0–8.0 | B.S.I.E. or I.M., will Train man with shop & Electrical Exp. | 2–5 | 30 | |
| 447 | Chem. Processing | WVa | | 10, 13, 18, 20, 30, 91 | Open | | 5– | | |
| 448 | Refining | Pa | | 11, 73 | 10.0– | | 10– | | |
| 449 | Electronics | Mass | | 30, 50, 70 | 6.0–8.0 | | 1–5 | | |
| 450 | Workshop | NY | | 10, 11, 38, 42, 43, 81 | | Supervisory Exp. | 3– | | |
| 451 | Garment | MW & SW | × | 10, 11, 14, 31, 42, 64, 65 | 6.8–7.8 | | 3– | 25 | 35 |
| 452 | Aircraft Assy. | NY | | 11, 13, 15 | 7.5– | | 4– | | |
| 453 | Rubber | Canada | | 10, 11, 13–15, 18, 19 | 4.8–6.0 | | 2– | 25 | 40 |
| 454 | Machinery Mfg. | Ind | | 11, 30 | 6.6–7.8 | | 2–4 | | 32 |
| 455 | Machinery Mfg. | Ind | | 43 | 6.6–7.8 | | 2–4 | | 32 |
| 456 | Machinery Mfg. | Ind | | 40, 41, 42 | 6.6–7.8 | | 2–4 | | 32 |
| 457 | Electronics | Ind | | 91, 11, 15, 30–33 | 9.0–10.0 | | 5–10 | 30 | 40 |
| 458 | Mdse.—Mail Order | Ill | | 92, 31, 36, 38, 43 | 12.0–14.0 | | 5–10 | 32 | 38 |
| 459 | Paper | Penn | | 11, 37, 42 | | Pulp & Paper Ind. Exp. | | | |
| 460 | Railway | Minn | | 19, 21, 23, 31, 37, 46, 90 | 10.4–13.6 | Supervisory Exp. | 2–4 | | |
| 461 | Paper | Ohio | | 10, 20, 70 | –13.0 | Container & Pkg. Exp. Preferred | 3– | | 45 |

*Key to Job Classifications*

| No. | Job Classification |
|---|---|
| 10 | Motion and Time Study |
| 11 | Methods Improvement |
| 12 | Suggestion Systems |
| 13 | Work Measurement and Perf. Stds. |
| 14 | Stop Watch Time Study |
| 15 | Std. Time Data Dev. & Applic. |
| 16 | Predeter. Elemental Time Stds. |
| 18 | Work Sampling |
| 19 | Estimating and Costing |
| 20 | Wage Payment |
| 21 | Incentive Plans |
| 22 | For Production Workers |
| 23 | For Non-Prod. Workers |
| 24 | For Supervisory Personnel |
| 26 | Job Evaluation |
| 28 | Wage Administration |
| 30 | Production Engineering |
| 31 | Production Control |
| 32 | Process Planning and Routing |
| 33 | Scheduling and Loading |
| 34 | Flow Process Charting |
| 35 | Inventory Control |
| 36 | Cost Anal. & Reduction |
| 37 | Statistical Quality Control |
| 38 | Budgetary Control, Standard Costs |
| 39 | Tool and Gage Design and Control |
| 40 | Plant Engineering |
| 41 | Plant Location & Expansion |
| 42 | Plant Layout |
| 43 | Material Handling |
| 44 | Machinery & Equipment |
| 45 | Specif., Select. & Eval. |
| 46 | Replacement |
| 47 | Automation |
| 48 | Plant Maintenance |
| 49 | Cap. Budget. Facil. Plan |
| 50 | Operations Research |
| 51 | System & Simulation with "Models" |
| 52 | Mathematical Analysis |
| 53 | Engr. Economy Studies |
| 54 | Auto. Data Proc. with Computers |
| 55 | Market Research & Forecasting |
| 60 | Industrial Relations |
| 61 | Personnel Administration |
| 62 | Personnel Testing |
| 63 | Personnel Training |
| 64 | Industrial Psychology |
| 65 | Labor Relations |
| 66 | Safety Engineering |
| 67 | Suggestion Systems |
| 70 | Systems and Procedures |
| 71 | Admin. & Operating Procedures |
| 72 | Organization Charts and Manuals |
| 73 | Records Admin. & Form Control |
| 80 | Product Design |
| 81 | Packaging |
| 90 | Management and Supervision |
| 91 | Industrial Engineering Supr. |
| 92 | Chief I. E. or Equiv. |
| 93 | Plant Engineer |
| 94 | Production Supervisor |
| 95 | Plant Mgr., Fact. Mgr., Works Mgr. |
| 96 | General Manager |

American Institute of Industrial Engineers, Inc.
145 N. High St.
Columbus 15, Ohio

Entered as
second-class matter

STEVENS RICE
UNIVERSITY MICROFILMS
313 N. FIRST STREET
ANN ARBOR, MICHIGAN C

**Industrial Engineering** is concerned with the design, improvement, and installation of integrated systems of men, materials and equipment; drawing upon specialized knowledge and skill in the mathematical, physical, and social sciences together with the principles and methods of engineering analysis and design, to specify, predict, and evaluate the results to be obtained from such systems.